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ANALYSIS OF THE SUDBURY ENVIRONMENTAL STUDY NETWORK

PRECIPITATION ACIDITY DATA, JUNE-SEPTEMBER 1978, 1979.

ISBN 0-7743-6840-3

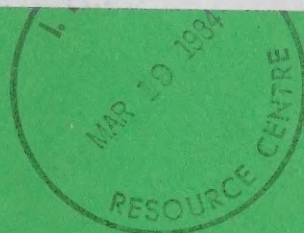
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June-September, 1978

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Minister

Gérard J. M. Raymond
Deputy Minister

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AIR RESOURCES BRANCH

Atmospheric Research and Special Studies Program

An Analysis of the Sudbury

Environmental Study Network Precipitation

Acidity Data

June-September, 1978

ARB-TDA-84-79



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ACKNOWLEDGEMENTS

The air parcel trajectory computations for this report were carried out by Mr. Joel Kurtz of the Air Quality and Meteorology Section, Air Resources Branch. This contribution, as well as his helpful discussions, are gratefully acknowledged. Thanks are also due to the Water Quality Section of the Laboratory Services Branch, Ontario Ministry of the Environment, for their special efforts in providing a rapid sample analysis and to the many volunteers in the Sudbury area who donated their time for collection of the event samples. Helpful comments on the text were provided by the Air Quality and Meteorology Section, The Water Quality Section of the Laboratory Services Branch, and the Northeastern Region of the Ministry of the Environment.

SUMMARY

Data from the Sudbury Environmental Study precipitation chemistry network, collected during the period June to September, 1978, were examined to see if there was any detectable decrease in precipitation acidity, or acid loading, during the smelter shutdown period in July and August. During this period, twenty event samplers, as well as seventeen Sangamo, wet-only, cumulative collectors, were operational. Most of the samplers were located within a radius of 100 km of Sudbury, and the comments in the present report are confined to this particular area.

The shutdown period data indicate that the "background" component to precipitation acidity, and acid loading, in the area is very significant and highly variable. Statistical analysis of the data reveals no significant difference in the precipitation free acidity (as indicated by the pH), or acid loading during the shutdown and operating periods. This suggests that, in the long term, the contribution of INCO and Falconbridge to the acidic precipitation problem in the Sudbury area may be relatively small with respect to that due to long range transport. However, at this time one cannot definitely conclude that smelting operations have no significant effect on the precipitation acidity and acid loading either within or beyond (e.g., Muskoka Lakes) the study area. The period considered in this report, although very interesting because it included the smelter shutdown, was only three months long. As more data become available, a more refined meteorological stratification than was possible here, as well as inspection of other supplementary information on sample chemical composition, should lead to a more accurate assessment of the impact of smelting operations.

CONCLUSIONS

The results obtained from the event and cumulative precipitation networks during June-September, 1978 have been examined and the following conclusions may be drawn:

- Even in the absence of smelter operations, there is a significant acid loading due to precipitation in the Sudbury area, which can only be attributed to long-range transport.
- The time and space variability of precipitation pH and acid loading in the area can be very large, and depends on air parcel history, local meteorology and storm dynamics.
- The data from the limited monitoring period considered here show no significant difference between shutdown and operating period precipitation acidities. A similar conclusion applies to acid loading. This observation suggests that the contributions due to INCO and Falconbridge to the acidic precipitation problem in the Sudbury area are, in the long term, relatively small compared to the component originating from long range transport. However, one cannot definitely conclude that smelter operations have no effect on the above parameters on a localized scale - the result is largely due to the sizeable acidic input from sources outside the Sudbury area.
- Final conclusions regarding the impact of smelter emissions on precipitation chemistry in the Sudbury area will have to await the completion of a more

detailed meteorological analysis than that in the present report (to identify air parcel trajectories corresponding to different emission heights), as well as an examination of supplementary data (precipitation metals concentrations, evidence of plume impingement from continuous SO₂ analyser records, etc.) to more clearly define exactly what happens to the local precipitation acidity when there is definite evidence of smelter emissions in the vicinity of the sampler. This work is now in progress.

1. INTRODUCTION:

In recent years there has been growing general concern over the acidity of precipitation, and its effects on the ecosystem. Increasing acidification of lakes has been noted in Scandinavia and the N.E. United States, and in the Sudbury and Muskoka areas of Ontario. There has been a great deal of speculation on the contributions of Sudbury smelter emissions to this problem. For this reason the Sudbury Environmental Study has undertaken several precipitation chemistry studies in the area.

This is a preliminary report describing some results of precipitation sampling in the Sudbury area, obtained by the Air Resources Branch's Special Studies Unit, as part of the Sudbury Environmental Study (SES). Attention is focussed on the INCO and Falconbridge shutdown period, and the weeks immediately preceding and following that period. Thus precipitation event data are included from June 21 to September 15, 1978. The Falconbridge smelter was shut down from July 1 - August 21, while INCO was not operating from July 17 - August 27.

An important objective of the SES precipitation sampling network is to assess the contribution of the INCO and Falconbridge smelting operations to the precipitation loading of acids and metals in the Sudbury area (i.e., within a radius of approximately 100 km of Sudbury). The shutdown period provided a rare opportunity to study precipitation quality in the absence of the major industrial polluters in the Sudbury basin. Precipitation pH and acid loading measurements were examined in the light of concurrent meteorological and smelter operating conditions, and as a result of this analysis, some preliminary conclusions were possible. However, these

conclusions should be regarded as tentative only, pending the collection of a larger data base once the current strike at INCO has ended. It should also be noted that present discussion is confined to a consideration of pH and acid loading, whereas the samples are currently being analysed for various other parameters (sulfate, nitrate, trace metals, etc.) which will probably serve to further elucidate the problem. Also, the conclusions of the present report do not necessarily apply to the related problem of metals deposition by precipitation, which is currently being assessed.

This report includes a brief description of the Air Resources Branch precipitation sampling network in the Sudbury area, and the data currently being generated by the network. The precipitation pH and acid loading data during the June 21-September 15 period are presented, and discussed with reference to meteorological and smelter operation variables. The results of air parcel trajectory analyses are included, to determine the origin of the air masses associated with the precipitation measurements. Conclusions are presented in Section 5.

2. PURPOSE:

The major objective of the work described in this report is to evaluate the relative contribution of local smelters and distant pollution sources to the acidic precipitation problem in the Sudbury area. The analysis is done by using data collected over a period of approximately three months, including the weeks when the smelters were shut down.

3. THE NETWORK:

3.1 Sample Collection -

Precipitation data were collected using two types of samplers-event (in which the collector was exposed for 24 hours)

and cumulative (in which the samples were collected over a period of approximately two weeks to one month).

Sangamo wet-only cumulative samplers (in which the 0.20 m diameter collection vessel is uncovered only during periods of precipitation) were used at seventeen locations, as indicated in Table 1 and Figure 1. These locations were selected to minimize, as far as possible, sample contamination due to local pollution sources and human activities (e.g., house chimneys, automobile traffic, etc.). All Sangamo sampler stations had a precipitation storage gauge to measure accumulated precipitation, while at some, continuous precipitation records were also obtained with Fisher-Porter and Tipping Bucket recording gauges. These are indicated in Table 1.

The event samples were collected by volunteers, using a polyethylene bag inserted in a polyethylene bucket approximately 0.4 m in diameter and 0.6 m deep. If precipitation was forecast on the 8 a.m. news, a fresh bag was placed in the bucket. If precipitation did indeed occur during the next 24 hours, the bag contents were poured into a plastic bottle and stored in the refrigerator pending chemical analysis. All possible precautions were taken to avoid sample contamination (e.g., disposable plastic gloves were used when handling bags; bags which had not collected any precipitation during 24 hours were not reused).

There were 20 event sites, details of which are summarized in Table 2 and Figure 2. With the exception of 3 sites at Thessalon (195 km), Ramsey (145 km) and North Bay (125 km), all sites were located within a radius of 75 km from the Sudbury area.

3.2 Chemical Analysis of Samples -

The collected, unfiltered samples were submitted for analysis to the Laboratory Services Branch of the Ministry of the Environment for the following parameters: pH, acidity, SO_4 , NO_3 , NH_4 , Ca, Si, Na, K, Mg, Cl, Br, Fe, Ni, Cu, Pb, Zn, Al, Cr, and Cd. The analysis methods used are summarized in Table 3. Analysis for parameters other than pH and acidity was too incomplete at the time of writing to warrant inclusion in this report.

It should be pointed out here that pH is a measure of the free acidic component of precipitation due to strong mineral acids (mainly sulfuric and nitric). It is equal to the negative logarithm of the free hydrogen ion concentration (in moles per litre). Total acidity, on the other hand, which is related to the total hydrogen ion, is a measure of the capacity of the precipitation sample to neutralize base, and is made up of the contribution due to strong acids, weak acids (carbonic acid, organic acids), hydrolyzable metallic salts, etc. The discussion in this report will focus on free hydrogen ions, as their concentration (H_f) is a measure of free acidity and is directly related to pH. Total acidity values (H_T) are included so that the relative contribution of strong acids and other acidic substances can be assessed.

The pH measurements are estimated to be accurate to within approximately 0.1 unit; the total acidity values, to within 0.002 mg H^+ /litre.

4. DISCUSSION:

It should be noted at the outset of the discussion that the data presented in Tables 4 to 40 and Figures A1-1 to A2-15 are raw data only. A number of objective criteria referred to in the text were applied to screen these data and the qualitative

and quantitative analyses are based on screened data only. Time constraints prevented the screened data from being presented at the time of writing but the data are now available at the Air Resources Branch.

4.1 Data Presentation -

4.1.1 Event Samples -

Tables 4 to 23 summarize the pH and acidity of the event samples collected. Not all samples were collected exactly over a 24 hour duration, but only those representing periods of less than 30 hours are included for calculations. The exact sampling periods are indicated in columns 1 to 3. The volume of precipitation is given in column 4. The sample pH was measured at Sudbury prior to sending samples to Toronto for analysis at LSB (- generally the agreement between Sudbury and LSB values was good). All reported pH values are those determined by MOE/LSB, except for a few cases in which insufficient volume was collected for both Sudbury and laboratory measurements. In these cases the Sudbury pH values are given. In Tables 4 to 23, these are indicated by (F). Results of acidity determination are incomplete because they were either not available from the MOE/LSB as yet at the time of writing or insufficient sample volume was collected for laboratory analysis. Free hydrogen ion H_F^+ and total hydrogen ion H_T^+ concentrations were calculated according to the following expressions:

$$\left[H_F^+ \right] = 10^{-pH} \times 10^3 \text{ (mg/L)}$$

and

$$\left[H_T^+ \right] = \text{Acidity}/50 \text{ (mg/L)}$$

The deposition of H_F and H_T are given in the last two columns in Tables 4 to 23. These values correspond to the product of precipitation volume and the hydrogen ion concentration and are normalized to one square meter (m^2) of deposition surface:

$$H_F^+ \text{ Deposition} = \text{Volume (L)} \times H_F \text{ (mg/L)} / \text{Collection Area of the Sampler (m}^2\text{)}$$

$$H_T^+ \text{ Deposition} = \text{Volume (L)} \times H_T \text{ (mg/L)} / \text{Collection Area of the Sampler (m}^2\text{)}$$

The accuracy of the deposition data will depend on the accuracy of the corresponding chemical analyses and also the collection efficiency of the samplers. Work is currently in progress to determine the latter, as a function of collector type and meteorological parameters. Pending the results of this work, the deposition rates in this report are estimated to be accurate to roughly 25%.

The data are represented graphically in Appendix 1 as Figures A1-1 to A1-20.

4.1.2. Cumulative Samples -

Cumulative sample data are presented in a similar format in Tables 24 to 40 . Before and after the shutdown period, samples were collected approximately once a month. During the period of interest, an attempt was made to collect semi-monthly samples corresponding to different source configurations. All parameters in the Tables carry their usual meaning. All pH values are MOE/LSB (Toronto) measurements.

It should be pointed out that, because sample collection efficiency is not 100%, the calculated H^+ depositions are probably somewhat lower than the true values. The calculated values will be refined when rain gauge data become available.

The results are presented graphically as Figures A2-1 to A2-15 in Appendix 2.

4.2 Data Interpretation -

Acidic precipitation is a complex phenomenon resulting from the combined effects of parcel history and composition, local emission conditions, and local meteorological conditions. The nature of the acidic components depends on the first two parameters whereas the precipitation volume is mainly a function of local meteorological conditions. Frequently, the precipitation pH value is referred to when the acidity of precipitation is discussed. This is misleading because it involves an implicit assumption that pH of precipitation is independent of precipitation volume, which in many cases is untrue due to the relative importance of different precipitation scavenging mechanisms. What is more important

in terms of the direct impact of acidic precipitation to the environment is the hydrogen ion deposition. Therefore, in this report, both the precipitation free hydrogen ion concentration (as measured by the pH), and the hydrogen ion deposition, will be considered.

Table 41 summarizes smelter operations at Sudbury during the period January - September, 1978. For the purposes of this report, "shutdown" will be taken to mean the period when both INCO and Falconbridge were not in operation (i.e., July 17 - August 21).

4.2.1. Event Data -

During the entire study period, each event with samples collected at more than five stations was analysed in detail with respect to the resultant rainfall field, the pH field, the free hydrogen ion deposition field, and the origin of the regional air mass arriving in Sudbury during the precipitation episode. Figures A3-1A to A3-11C in Appendix 3 illustrate the rainfall, pH, and H^+ deposition fields for each event.

All contours in Figures A3-1A to A3-11C were drawn manually using a linear interpolation scheme. The arrows on each map represent the direction of air flow into the region. This direction was obtained using an air parcel trajectory calculation on the 850 millibar pressure level of the atmosphere, modified by a counterclockwise rotation of 15° to better represent the average flow in the mixing layer of the atmosphere*. For each event, a trajectory for air entering the region was determined for both the beginning and the end of the sampling period (roughly

*This method is similar to that of Johnson et al. ("The European Regional Model of Air Pollution (EUROMAP) and its Applications to Transfrontier Air Pollution", Proc. of the 7th International NATO/CCMS Meeting on Air Pollution Modelling, September, 1976).

0800 EST). The angle of deviation between the beginning and end trajectories is given on each map inside the arrows. This deviation is an indicator of the variability of the flow field during the sampling period.

It is important to note that the arrows indicated on each map represent only the general inflow to the region within the mixed layer. It is possible that the trajectory of emissions from local sources could be different from that implied by the mixed layer trajectory. Such behavior is due to the vertical variation of the wind field and the differing heights of local source emissions.

Two methods of analysis were employed to evaluate the effect of the smelter shutdown period on the acidity of precipitation in the Sudbury area. The first method was strictly qualitative and involved a comparison of the rainfall, pH, and H^+ deposition fields for individual events during both the source shutdown and source operating periods. The second method was quantitative or statistical. It consisted of a station-by-station comparison of pH and H^+ deposition data for the operating and shutdown periods. Statistical tests of significance were carried out to determine if real differences were observable. The results of both studies are discussed in the following section.

4.2.1.1. Qualitative Analysis -

Since the deposition of free hydrogen ions is a more important factor than precipitation pH in impact on the environment, it is necessary to examine both parameters which affect that deposition field,

namely the rainfall amount and the H^+ concentration (or pH) of the rainfall. Rainfall fields are discussed initially.

The rainfall field for each event is illustrated using contour lines on Figures A3-1A to A3-11A in Appendix 3. The data represent the depth of rainfall falling on a collection area of 1411 cm^2 (area of the collector mouth). Examination of the tabulated data shows that for a given event, rainfall amounts often varied by an order of magnitude on a regional scale. This spatial variability is highly dependent on local meteorology and storm dynamics and severely affects the H^+ deposition pattern (see below). The location of the maximum rainfall varied throughout the entire study period and no trend was visible. One characteristic of the rainfall fields observed during the study period was the tendency for rainfall amount to increase towards the east and southeast. It may be pointed out here that the distribution of rainfall in the study area, and in Ontario in general, is a factor deserving close attention. Since hydrogen ion deposition is a function of the rainfall amount, the potential for acid loading to a given area increases with the rainfall received, all else being constant.

Consider now the pH field observed in the event sampling. The pH distribution for each rainfall event during the shutdown period shows that the spatial and temporal variability of the rainfall free acidity is extremely large. The tabulated data and the pH contour maps illustrate that the range of pH's in the Sudbury area can change significantly from event to event, and, most importantly, the variability of pH within a radius of 80 Km from Sudbury is large.

An examination of the pH data from the operating period showed no detectable effect of smelter emissions, largely because of the large "background" spatial and temporal variability of the pH indicated above in the discussion of the shutdown period data. Regional transport and storm dynamics can combine to cause such a large variation in the rainfall acidity distribution that it becomes extremely difficult to definitively identify contributions from local sources by an analysis such as the present one.

Consider finally the acid deposition data. The large variability in the rainfall amount and pH fields discussed above is reflected in the deposition field. Data for the shutdown period are shown with contour lines in Figures A3-1C to A3-11C. Examination of these figures shows that the H^+ deposition pattern was definitely different from the rainfall and pH patterns. In addition, the spatial variation of H^+ deposition throughout the shutdown period is generally higher than either the pH or rainfall variability. No trend in the location of the deposition maximum was visible but a very strong gradient throughout the Sudbury area was observed.

In summary, inspection of operating and shutdown data leads to the qualitative assessment that there was no measurable difference in pH or hydrogen ion deposition. Meteorological factors and long-range transport affect the local deposition so greatly that influences due to smelter operation cannot be detected from the above analysis of the data. However, in general terms, the measured values of pH and acid deposition are significant, and do indicate that atmospheric loading to the area due to long-range transport is large.

4.2.1.2 Quantitative Analysis -

The conclusions arrived at in the qualitative analysis discussed above, regarding the impact of smelter emissions as indicated by precipitation pH and acid loading measurements, were borne out by a statistical analysis of the data. This was carried out as follows:

The event data from each station were separated into two groups - one for the shutdown period (July 17-August 21), the other for the rest of the sampling period. Only data which met the criterion of a 24 ± 6 hour collection period were included. An examination of all the free hydrogen ion concentration and deposition data for each period showed that the values are best represented by a log-normal distribution (and that the pH values are normally distributed). The geometric means and standard deviations, as well as the 95% confidence limits of the means, were computed. The t-test was used to obtain the latter values. Results are shown in Table 42, in which are also included the corresponding statistics of the pH measurements, obtained by assuming a normal distribution.

An examination of the values in Table 42 shows that there is no significant difference between precipitation pH, and free hydrogen ion concentration and deposition, during the plant shutdown and operating periods. Thus these data, gathered over a three-month period, suggest that the acidity of rainfall and the acid loading to the Sudbury region are so dominated by the long-range transport component, and by variations due to storm dynamics, that the effects of local emissions are lost in the "background noise" when data for the whole region are considered.

4.2.2 Cumulative Network Data -

Contour maps of the pH distribution for different smelter operating conditions, as obtained from the Sangamo sampler data are shown in Figures A4-1 through A4-5. Qualitative comparisons of the pH fields for each source period lead to the following observations:

- (i) Very strong pH gradients are observable throughout the sampling region during both the shutdown and operational periods.
- (ii) The minimum pH observed throughout the entire sampling period occurred during the shutdown period.
- (iii) The spatial and temporal variability of cumulative pH was very high (as one would expect from the event data).
- (iv) The pH's measured during the shutdown period are relatively low indicating that the contribution of non-local sources to rainfall acidity is significant.
- (v) With the data currently available, the general variability of pH is too large to allow a separation, and assessment, of the contribution of Sudbury sources to the acidity of precipitation problems.

The H_F^+ deposition fields of the cumulative data show the large spatial variability expected from the pH and volume fields. There does appear to be a trend, however, in the H_F^+ deposition fields, namely, a gradient of increasing deposition exists from the Northwest to the Southeast. With more data, it may be possible to confirm this trend in the long term, and it is somewhat premature to state that areas to the southeast of Sudbury have a greater potential for acidic loading than areas to the northwest.

Figures A2-1 to A2-15 in Appendix 2 show the temporal variation of volume, pH, acidity, H_F^+ and H_T^+ deposition at each Sangamo sampling station. It can be observed that the pH's during the shutdown period were not greatly different from those obtained during the rest of the year. In fact, at several stations the pH's were lower during part of the shutdown period than during operating periods. Such behaviour is in general agreement with observations obtained using the event network data: ie., acidity of the precipitation samples in the Sudbury area seems to be dominated by local meteorological factors and long-range transport.

It is interesting to note that Figures A2-1 to A2-15 indicate that the summertime acid loadings are higher than wintertime loadings. This is more a reflection of the precipitation amount than other factors.

TABLE 1: Details of the Cumulative Precipitation Sampling Network

STATION	STARTING DATE	PRECIPITATION SAMPLER		RAIN GAUGE		STORAGE GAUGE
		SANGAMO	AEROCHEMETRIC	FISHER PORTER	TIPPING BUCKET	
Burwash	Dec/77	X		X	X	X
Lake Panache	Dec/77	X				X
Windy Lake	Dec/77	X		X		X
Hammer	Dec/77	X				X
Killarney	Dec/77	X			X	X
Halfway Lake	Sept/78		X			X
Gowganda	Dec/77	X			X	X
Elliott Lake	Dec/77	X		X		X
North Bay	Dec/77	X				X
Parry Sound	Dec/77	X		X		X
St. Charles	Dec/77	X				X
Martin River	June/78	X		X		X
Florence Lake	Sept/78		X			X
Ramsey	June/78	X				X
Graveyard Lake	Sept/78		X	X		X
Chiniguchi Lk.	July/78		X	X		X
Massey	June/78	X				X
River Valley	July/78	X				X
Lively	Dec/78	X				X
Noelville	June/78	X				X
Bear Island	June/78	X				
Portage Lake	Nov/78	X				X

TABLE 2: Details of the Event Sampling Network

Station	Starting Date (First Samples)	Tipping Bucket Gauge	Fisher Porter Gauge
A. Ramsey	June 21/78		
B. Burwash	June 28/78		X
C. New Sudbury	June 26/78		
D. Long Lake	June 26/78		
E. Wanup	June 22/78		
F. Lively	July 12/78		
G. Azilda	Aug. 18/78		
H. Skead	July 22/78		
I. McCharles Lake	June 26/78		
J. Windy Lake	July 7/78		X
K. Lake Wanapatei	July 7/78		
L. Verner	July 8/78		
M. North Bay	Aug. 16/78		
N. Killarney	July 8/78	X	
O. Charleton Stn.	July 15/78		
P. Markstay	July 8/78		
Q. Lake Panache	July 7/78		
R. Thessalon	July 18/78		
S. Laurentian U.	July 19/78	X	
T. Grundy Park	July 13/78		

Table 3: Details of precipitation sample chemical analysis:

Parameter	Analysis Method
pH	Radiometer (pH electrode)
Total Acidity	NaOH titration to pH 8.3 (results generally expressed as mg Ca CO ₃ /litre).
SO ₄	Originally MTB method; presently Dionex ion-exchange chromatograph
NO ₃	Originally Cd column and hydrazine methods; presently, ion-exchange chromatography
NH ₄	Nitroprusside method
Cl, F, Br	Ion-exchange chromatography
Si	Molybdenum blue method
Ca, Mg, Na, K	Flame atomic absorption
Fe, Ni, Cu, Pb, Zn, Al, Cr, Cd	Flameless atomic absorption

EVENT SAMPLING ANALYSIS RESULTS

TABLE 4:
Event Sampling Results for June -
September, 1978 at Ramsey

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION NAME : RAMSEY

PAGE : 1

PERIOD START/END	TIME (HR.)		VOL. (ML.)	PH	ACIDITY AS CaCO3 (MG/L)	HF (MG/L)	HT (MG/L)	DEPOSITION	
	START	END						HF (MG/M2)	HT (MG/M2)
JUN21-JUN22, 78	2000	1830	325	4.95	3.14	0.011	0.053	0.028	0.145
JUN22-JUN23, 78	1830	1030	65						
JUN27-JUN28, 78	1830	1500	65						
JUL 5-JUL 6, 78	2000	2000	35	3.80		0.158	0.033		
JUL 6-JUL 7, 78	2030	1830	783	3.71	10.90	0.185	0.218	1.082	1.210
JUL 7-JUL 8, 78	1830	1100	783	4.14	5.72	0.072	0.114	0.402	0.835
JUL 18-JUL 19, 78	1445	1345	150	3.53		0.295		0.314	
AUG 8-AUG 9, 78	900	900	60						
AUG 16-AUG 17, 78	900	900	920	4.80	1.23	0.016	0.025	0.103	0.160
AUG 18-AUG 19, 78	900	900	4795	4.23	2.59	0.059	0.052	2.001	1.760
AUG 22-AUG 23, 78	900	900	1055	4.47		0.034		0.254	
AUG 23-AUG 24, 78	900	900	2010	4.45		0.035		0.747	
AUG 28-AUG 29, 78	830	800	1920	4.80		0.016		0.216	
AUG 29-AUG 30, 78	900	900	385	4.68		0.022		0.060	
SEP 1-SEP 2, 78	900	800	120	4.55		0.028		0.026	
SEP 6-SEP 7, 78	900	900	280	4.15		0.071		0.120	
SEP 14-SEP 15, 78	900	1000	1030	4.35		0.045		0.226	

EVENT SAMPLING ANALYSIS RESULTS

TABLE 5:

Event Sampling Results for June -
September, 1978 at Burwash

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION NAME : BURWASH

PAGE : 1

PERIOD START/END	TIME (HR.)		VOL (ML.)	PH	ACIDITY AS CaCO3 (MG/L)	HF (MG/L)	HT (MG/L)	DEPOSITION	
	START	END						HF (MG/M2)	HT (MG/M2)
JUN27-JUN28, 78	815	1615	65						
JUN28-JUN29, 78	1615	810	325	5.39	4.21	0.004	0.084	0.009	0.194
JUL 7-JUL 8, 78	2300	600	310						
JUL 8-JUL 9, 78	802	800	783	4.05	9.70	0.089	0.194	0.494	1.076
JUL 9-JUL 10, 78	2530	800	310	4.16		0.069		0.152	
JUL 10-JUL 11, 78	800	700	318	3.68	19.00	0.209	0.380	0.471	0.859
JUL 13-JUL 14, 78	600	530	1240	3.81	12.30	0.155	0.246	1.361	2.162
JUL 16-JUL 18, 78	1230	700	783	3.81	10.90	0.155	0.218	0.859	1.210
JUL 19-JUL 20, 78	100	800	358	4.39		0.041		0.103	
JUL 22-JUL 23, 78	800	800	1240	3.76	11.09	0.174	0.222	1.527	1.949
JUL 28-JUL 28, 78	100	800	100	4.16		0.069		0.049	
JUL 26-JUL 27, 78	1415	800	1415	4.10	6.61	0.079	0.112	0.796	1.125
JUL 28-JUL 29, 78	800	800	495	4.27	4.15	0.054	0.083	0.188	0.291
JUL 29-JUL 30, 78	800	800	695	4.05	5.16	0.089	0.103	0.439	0.508
JUL 31-AUG 1, 78	800	800	65						
AUG 02-AUG 03, 78	800	800	1720	3.94	10.49	0.115	0.210	1.399	2.557
AUG 08-AUG 09, 78	800	800	495	4.93	5.25	0.012	0.105	0.041	0.368
AUG 15-AUG 16, 78	700	700	925	3.95	10.74	0.112	0.215	0.735	1.408
AUG 16-AUG 17, 78	700	700	35	3.95		0.112		0.028	
AUG 17-AUG 18, 78	700	700	35	5.45(F)		0.004		0.001	

TABLE 5 (cont'd)

Event Sampling Results for June -
September, 1978 at Burwash (cont'd)

EVENT SAMPLING ANALYSIS RESULTS

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MINISTRY OF ENVIRONMENT

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PAGE : 2

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SES - TDA - ARB
MINISTRY OF ENVIRONMENT

Event Sampling Results for June -
September, 1978 at New Sudbury

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EVENT SAMPLING ANALYSIS RESULTS

TABLE 8:

Event Sampling Results for June -
September, 1978 at Wanup

SES - TDA - ARB

MINISTRY OF ENVIRONMENT

PAGE : 1

STATION NAME : WANUP

PERIOD START/END	TIME (HR.)		VOL (ML.)	PH	ACIDITY AS CaCO3 (MG/L)	HF (MG/L)	HT (MG/L)	DEPOSITION	
	START	END						HF (MG/M2)	HT (MG/M2)
JUN22-JUN22,78	1755	2130	65						
JUN26-JUN27,78	800	700	438	4.62	4.90	0.024	0.098	0.074	0.304
JUN28-JUN29,78	1640	900	100	6.46		0.000		0.000	
JUL 7-JUL 8,78	2300	1600	160	3.82		0.151		0.172	
JUL13-JUL13,78	800	1600	438	3.82	12.60	0.151	0.252	0.470	0.782
JUL18-JUL19,78	1340	800	160	4.51		0.031		0.035	
JUL22-JUL23,78	1900	900	1200	3.95	5.27	0.112	0.105	0.954	0.696
JUL26-JUL27,78	1700	800	1245	4.17	8.17	0.068	0.123	0.596	1.089
JUL27-JUL28,78	1000	800	1330	4.40	3.48	0.040	0.070	0.375	0.656
JUL29-JUL30,78	800	800	1270	4.04	4.71	0.091	0.094	0.821	0.848
AUG 2-AUG 3,78	800	800	2125	3.65	11.68	0.224	0.238	3.371	3.578
AUG13-AUG14,78	800	800	1040	4.24	8.42	0.058	0.168	0.424	1.241
AUG15-AUG16,78	800	800	290	3.93(F)	10.13	0.117	0.203	0.242	0.416
AUG18-AUG17,78	800	900	140	4.24(F)	8.71	0.058	0.134	0.057	0.133
AUG18-AUG18,78	800	800	1325	4.15	8.50	0.071	0.170	0.665	1.596
AUG23-AUG24,78	800	800	8605	4.15	4.96	0.071	0.098	4.317	6.049
AUG27-AUG28,78	800	800	2933	4.10	5.55	0.079	0.111	1.651	2.307
AUG28-AUG29,78	800	800	1153	4.35	4.32	0.045	0.088	0.385	0.708
AUG29-AUG30,78	800	800	550	4.09		0.081		0.517	
SEP 2-SEP 3,78	800	800	6204	4.12		0.078		3.335	

[illegible]

TABLE 11:

Event Sampling Results for June - September, 1978 at Skead

EVENT SAMPLING ANALYSIS RESULTS

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MINISTRY OF ENVIRONMENT

STATION NAME : SEAD

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[illegible]

EVENT SAMPLING ANALYSIS RESULTS

TABLE 12:

Event Sampling Results for June -
September, 1978 at McCharles Lake

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION NAME : MCCHARLES LAKE

PAGE : 1

PERIOD START/END	TIME (HR.)		VOL (ML.)	PH	ACIDITY AS CaCO3 (MG/L)	HF (MG/L)	HT (MG/L)	DEPOSITION	
	START	END						HF (MG/M2)	HT (MG/M2)
JUN 26 - JUN 27, 1978	1100	1330	515	4.53	4.48	0.030	0.090	0.108	0.327
JUL 13-JUL 14, 78	815	800	185	3.48(F)		0.331		0.434	
JUL 14-JUL 15, 78	1500	1400	887	4.05	5.94	0.088	0.119	0.548	0.730
JUL 19-JUL 20, 78	1930	1830	229	4.19		0.065		0.105	
JUL 22-JUL 23, 78	1245	1230	2835	3.82		0.151		3.041	
JUL 26-JUL 27, 78	845	845	995	4.20	6.73	0.063	0.135	0.445	0.949
JUL 27-JUL 28, 78	845	900	945	4.42	3.92	0.038	0.078	0.255	0.525
JUL 29-JUL 30, 78	900	845	485	4.22(F)		0.060		0.207	
AUG 2-AUG 3, 78	815	800	2490	3.65	11.55	0.224	0.231	3.950	4.076
AUG 15-AUG 16, 78	2200	2200	1755	4.32	6.22	0.048	0.124	0.595	1.547
AUG 23-AUG 24, 78	800	800	4365	3.85	7.59	0.141	0.152	4.369	4.695
AUG 27-AUG 28, 78	800	800	2215	4.25	7.17	0.056	0.143	0.883	2.251
AUG 29-AUG 30, 78	800	800	1625	4.49		0.032		0.373	
SEP 4-SEP 5, 78	2000	815	1115	5.30		0.005		0.040	
SEP 8-SEP 7, 78	900	730	200	3.88		0.132		0.187	
SEP 8-SEP 9, 78	830	730	275	4.05		0.089		0.174	
SEP 9-SEP 10, 78	815	745	825	4.11		0.078		0.454	
SEP 10-SEP 11, 78	805	735	350	4.61		0.025		0.061	
SEP 14-SEP 15, 78	830	800	2490	3.90		0.128		2.221	

TABLE 13:

Event Sampling Results for June - September, 1978 at Windy Lake

EVENT SAMPLING ANALYSIS RESULTS

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MINISTRY OF ENVIRONMENT

PAGE : 1

STATION NAME : WINDY LAKE

STATION NAME : WINDY LAKE

[illegible]

EVENT SAMPLING ANALYSIS RESULTS

TABLE 15:

Event Sampling Results for June -
September, 1978 at Verner

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION NAME : VERNER

PAGE : 1

PERIOD START/END	TIME (HR.)		VOL (ML.)	PH	ACIDITY AS CaCO3 (MG/L)	HF (MG/L)	HT (MG/L)	DEPOSITION	
	START	END						HF (MG/M2)	HT (MG/M2)
JUL08-JUL09,78	815	700	438	3.82		0.151		0.470	
JUL13-JUL14,78	800	1530	2140	3.97	9.05	0.107	0.181	1.625	2.745
JUL18-JUL19,78	1300	800	805	3.63	12.22	0.234	0.244	1.337	1.384
JUL22-JUL23,78	1800	1000	810	3.76	12.44	0.174	0.248	1.121	1.604
JUL26-JUL27,78	830	830	4425	5.15	3.81	0.007	0.076	0.222	2.389
JUL27-JUL28,78	830	830	440	4.26	3.41	0.055	0.058	0.171	0.213
JUL28-JUL29,78	830	830	485	4.87	2.75	0.021	0.055	0.075	0.183
JUL29-JUL30,78	830	900	1120	4.05	3.86	0.088	0.078	0.707	0.628
AUG 8-AUG 9,78	830	830	430	6.15	1.68	0.001	0.034	0.002	0.103
AUG15-AUG16,78	830	830	430	4.60	3.64	0.025	0.073	0.077	0.222
AUG18-AUG19,78	830	830	3425	4.29	3.78	0.051	0.078	1.245	1.835
AUG23-AUG24,78	830	830	5855	4.25	1.21	0.058	0.024	2.253	0.970
AUG29-AUG30,78	830	830	495	4.31		0.048		0.172	
SEP 2-SEP 3,78	830	830	1705	4.25		0.056		0.679	
SEP 6-SEP 7,78	830	830	265	3.84		0.145		0.271	
SEP10-SEP11,78	815	815	1870	4.36		0.044		0.609	

TABLE 16:

Event Sampling Results for June -
September, 1978 at North Bay

EVENT SAMPLING ANALYSIS RESULTS

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MINISTRY OF ENVIRONMENT

STATION NAME :: NORTH BAY

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[illegible]

TABLE 17:

Event Sampling Results for June -
September, 1978 at Killarney

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION NAME : KILLARNEY

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[illegible]

Event Sampling Results for June - September, 1978 at Charleton Stn.

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

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EVENT SAMPLING ANALYSIS RESULTS

TABLE 19:

Event Sampling Results for June - September, 1978 at Markstay

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MINISTRY OF ENVIRONMENT

STATION NAME : MARKSTAY

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EVENT SAMPLING ANALYSIS RESULTS

TABLE 20:

Event Sampling Results for June -
September, 1978 at Lake Panache

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION NAME : LAKE PANACHE

PAGE : 1

PERIOD START/END	TIME (HR.)		VOL (ML.)	PH	ACIDITY AS CaCO3 (MG/L)	H _F (MG/L)	H _T (MG/L)	DEPOSITION	
	START	END						H _F (MG/M2)	H _T (MG/M2)
JUN 6-JUN10,78	700	1045	1640	5.33	10.10	0.005	0.202	0.054	2.347
JUL12-JUL13,78	915	700	100	4.80		0.010		0.011	
JUL13-JUL14,78	700	945	783	3.81	11.50	0.155	0.230	0.859	1.278
JUL18-JUL19,78	700	945	438	3.66	14.30	0.219	0.286	0.678	0.888
JUL19-JUL20,78	700	700	783	4.20	3.71	0.063	0.074	0.350	0.412
JUL21-JUL24,78	945	1005	2131	4.34	4.53	0.046	0.092	0.690	1.388
JUL26-JUL27,78	930	710	830	4.16	8.28	0.089	0.126	0.458	0.828
JUL28-AUG 1,78	945	715	1150	4.06	6.73	0.087	0.135	0.710	1.097
AUG 2-AUG 3,78	945	730	1765	3.47	13.43	0.339	0.269	4.238	3.359
AUG16-AUG17,78	900	830	720	4.60	4.76	0.025	0.095	0.128	0.486
AUG18-AUG19,78	930	930	2805	4.05	7.89	0.088	0.158	1.771	3.136
AUG23-AUG24,78	930	725	4035	3.94	8.26	0.115	0.165	3.203	4.723
AUG25-AUG26,78	930	930	1350	3.85	8.74	0.141	0.175	1.351	1.672
AUG28-AUG29,78	730	730	575	4.02	3.78	0.095	0.075	0.389	0.306
SEP 1-SEP 3,78	930	945	645	4.13		0.074		0.339	
SEP 3-SEP 5,78	945	800	135	4.74		0.018		0.017	
SEP 6-SEP 7,78	930	900	1506	4.70		0.020		0.213	
SEP 8-SEP10,78	900	1020	980	4.23		0.059		0.413	
SEP10-SEP11,78	1020	1500	176	3.90		0.128		0.158	
SEP11-SEP12,78	1500	800	325	4.43		0.039		0.068	

MINISTRY OF ENVIRONMENT

TABLE 20 (cont'd):
Event Sampling Results for June -
September, 1978 at Lake Panache

STATION NAME : LAKE PARAYE

PAGE : 2

[illegible]

Event Sampling Results for June - September, 1978 at Thessalon

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

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Monthly (Sangamo) Sampling Results for 1978 at Burwash

SEEN - TDA - ARS

MINISTRY OF ENVIRONMENT

STATION NAME : BURWASH

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[illegible]

Monthly (Sangamo) Sampling Results for 1978 at Panache

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MINISTRY OF ENVIRONMENT

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[illegible]

Monthly (Sangamo) Sampling Results
for 1978 at Windy Lake

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MINISTRY OF ENVIRONMENT

STATION NAME : WINDY LAKE

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[illegible]

Monthly (Sangamo) Sampling Results for 1978 at Hanmer

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MINISTRY OF ENVIRONMENT

STATION NAME : HAMMER

Page 11

[illegible]

Monthly (Sangamo) Sampling Results for 1978 at Killarney

MONTHLY PRECIPITATION SAMPLE RESULTS

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MINISTRY OF ENVIRONMENT

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STATION NAME : KILLBUCK

[illegible]

TABLE 29:

Monthly (Sangamo) Sampling Results for 1978 at St. Charles

MONTHLY PRECIPITATION SAMPLE RESULTS

SES - TDH - ARRB

MINISTRY OF ENVIRONMENT

STATION NAME : ST. CHARLES

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[illegible]

Monthly (Sangamo) Sampling Results for 1978 at Gowganda

MONTHLY PRECIPITATION SAMPLE RESULTS

BRB - TOT - SEE

MINISTRY OF ENVIRONMENT

STATION NAME : GOWANDA

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Monthly (Sangamo) Sampling Results
for 1978 at Elliott Lake

SES - TDA - ARS

MINISTRY OF ENVIRONMENT

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STATION NAME : ELLIOTT LAKE

[illegible]

TABLE 34:

Monthly (Sangamo) Sampling Results for 1978 at Marten River

MONTHLY PRECIPITATION SAMPLE RESULTS

SEES - TDA - ARB

MINISTRY OF ENVIRONMENT

PAGE : 1

STATION NAME : MARTEN RIVER

[illegible]

Monthly (Sangamo) Sampling Results MONTHLY PRECIPITATION SAMPLE RESULTS
for 1978 at Chiniguchi

MINISTRY OF ENVIRONMENT

STATION NAME : CHINIGUCHI

[illegible]

Monthly (Sangamo) Sampling Results for 1978 at River Valley

SES - TDA - ARS

MINISTRY OF ENVIRONMENT

STATION NAME : RIVER VALLEY

135

[illegible]

TABLE 39:

Monthly (Sangamo) Sampling Results MONTHLY PRECIPITATION SAMPLE RESULTS
for 1978 at Bear Island

SSS - TDR - FRRS

MINISTRY OF ENVIRONMENT

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STATION NAME : BEAR ISLAND

[illegible]

Monthly (Sangamo) Sampling Results
for 1978 at Noelville

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MINISTRY OF ENVIRONMENT

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STATION NAME : NOELVILLE

[illegible]

TABLE 41

Operation Conditions of Major Industries
in Sudbury for 1978

Time	Industry	Operating Conditions		
		Normal	Shutdown	Strike
Jan-Jun	INCO	X		
	Falconbridge	X		
July 1- Aug 21	Falconbridge		X	
July 17 - Aug. 27	INCO		X	
Sept.16 -	INCO			X

TABLE 42: pH and H_F Concentration and Deposition
Statistics for the Shutdown and Operating
Periods*

<u>PARAMETER</u>	<u>SHUTDOWN</u>	<u>OPERATING</u>
H_F^+ Concentration	Geo. Mean = 0.066 mg/l Upper Limit(95%)=0.079 Lower Limit(95%)=0.055 Geo. Std. Dev. = 2.36 No. of Values = 96	Geo. Mean = 0.063 mg/l Upper Limit(95%)=0.071 Lower Limit(95%)=0.056 Geo. Std. Dev. = 2.00 No. of Values = 123
H_F^+ Deposition	Geo. Mean = 0.58 mg/m ² Upper Limit(95%) = 0.72 Lower Limit(95%) = 0.47 Geo. Std. Dev. = 2.86 No. of Values = 93	Geo. Mean = 0.66 mg/m ² Upper Limit(95%)=0.78 Lower Limit(95%)=0.56 Geo. Std. Dev. = 2.58 No. of Values = 123
pH	Mean = 4.18 Upper Limit(95%)= 4.26 Lower Limit(95%)= 4.10	Mean = 4.20 Upper Limit(95%)= 4.25 Lower Limit(95%)= 4.15

*Event data from all stations meeting the criterion of a 24 ± 6 hour collection period.

In a few additional cases, where there was a large difference between pH values as measured in the field and the laboratory, the data were excluded from the statistical analysis (-in most of these cases, there was evidence of sample contamination).

FIGURE 1: The Cumulative Precipitation - Sampling Network

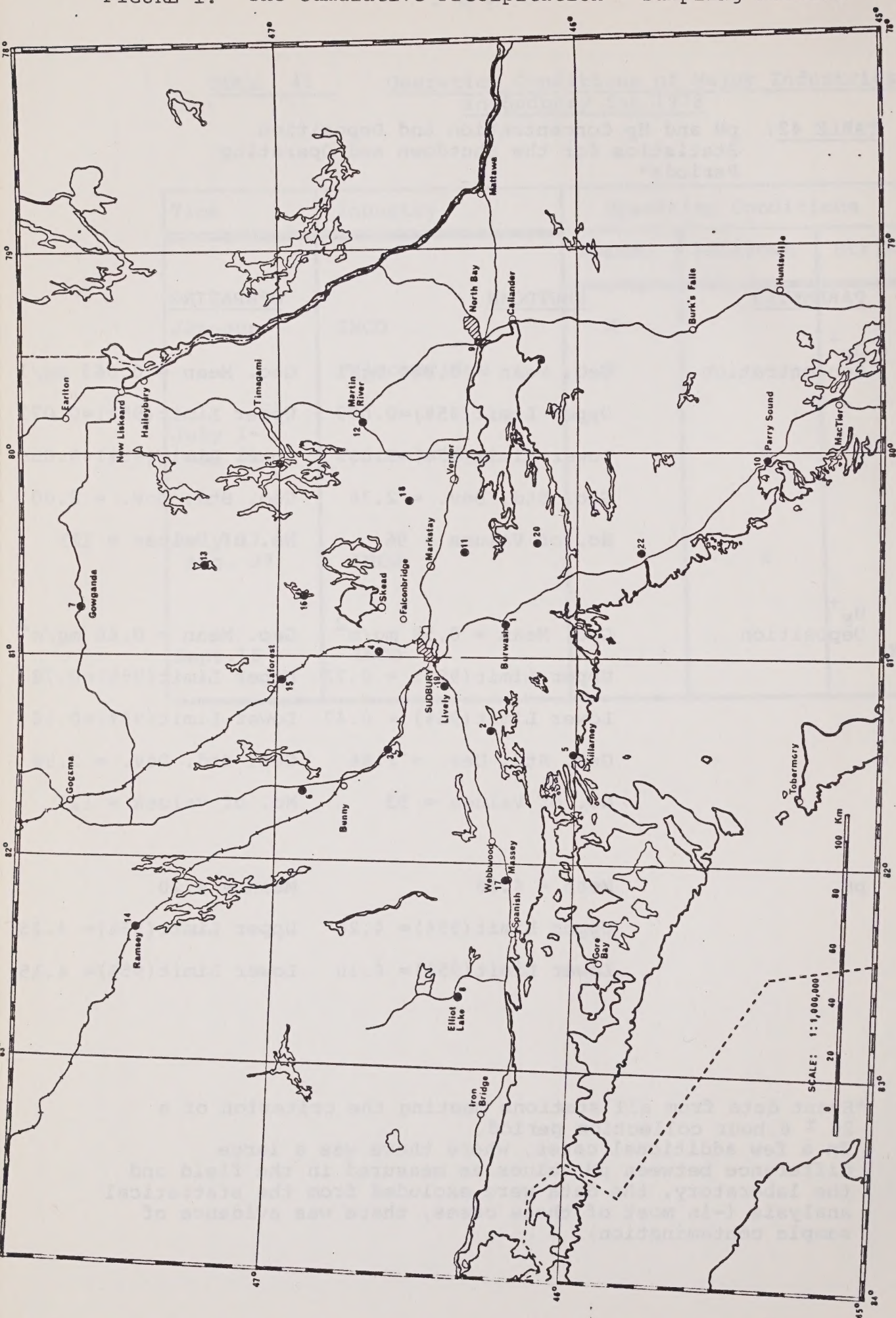
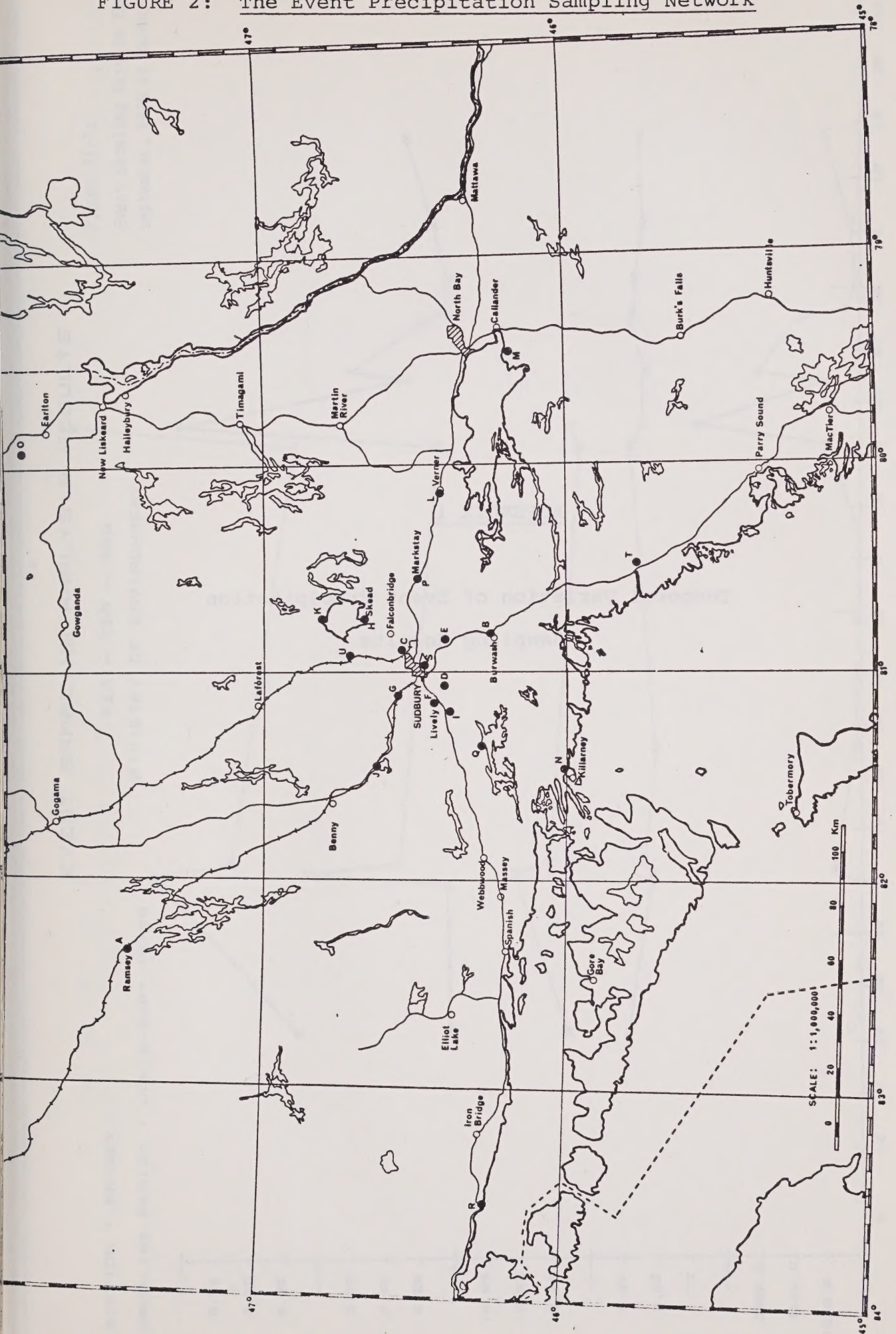


FIGURE 2: The Event Precipitation Sampling Network



APPENDIX 1

Temporal Variation of Event Precipitation

Sampling Results

EVENT SAMPLING ANALYSIS RESULTS

STATION : RAMSEY

SAMPLING PERIOD : JUN15-SEPT.15,78

SES - TDA - ARB

MINISTRY OF ENVIRONMENT

FIGURE A1-1:

Event Sampling Results for June - September, 1978 at Ramsey

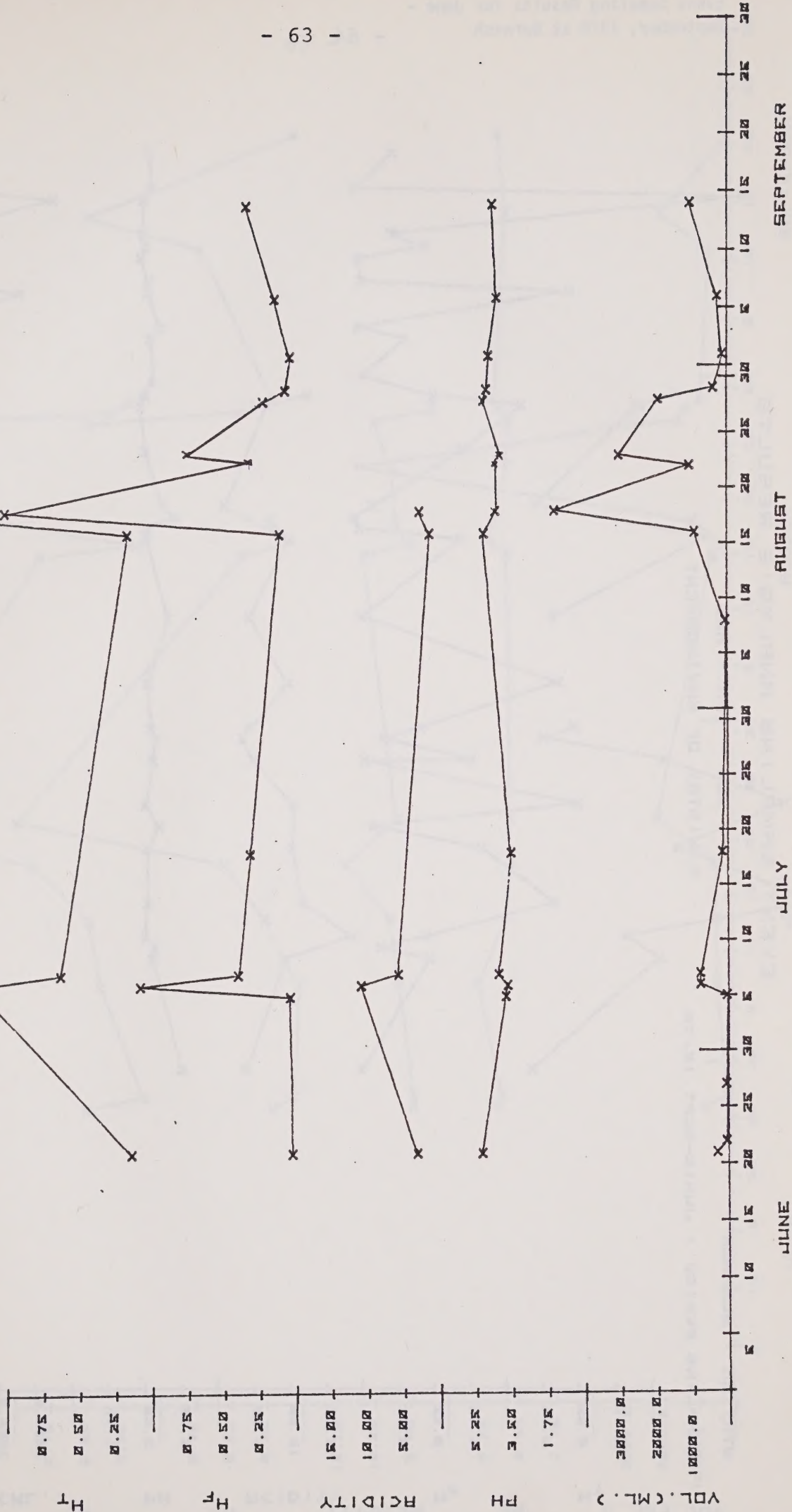
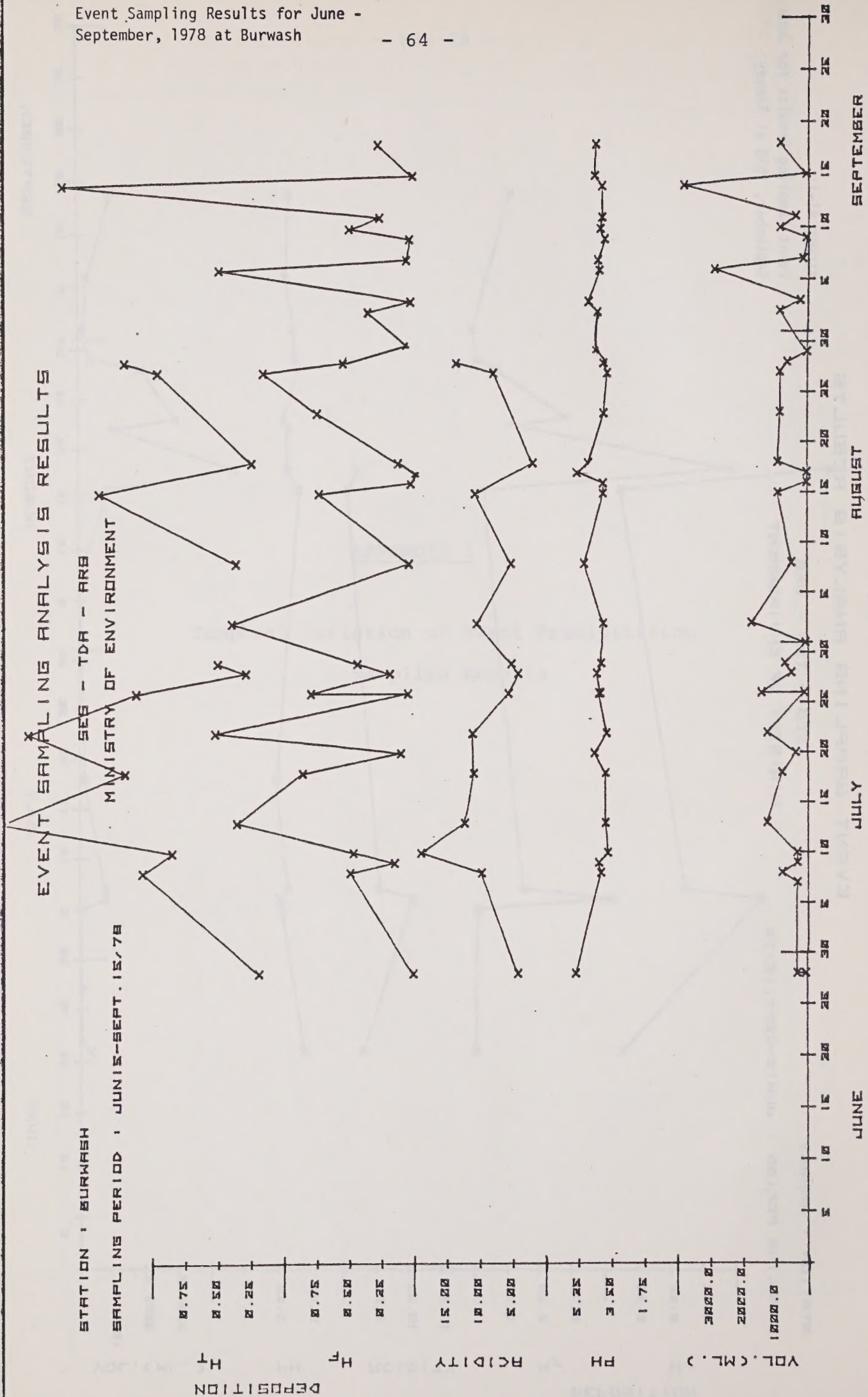


FIGURE AT-2.

Event Sampling Results for June -
September, 1978 at Burwash



EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-3:
Event Sampling Results for June -
September, 1978 at New Sudbury

STATION : NEW SUDBURY

SAMPLING PERIOD : JUN15-SEPT.15.78

SES - TDA - ARB

MINISTRY OF ENVIRONMENT

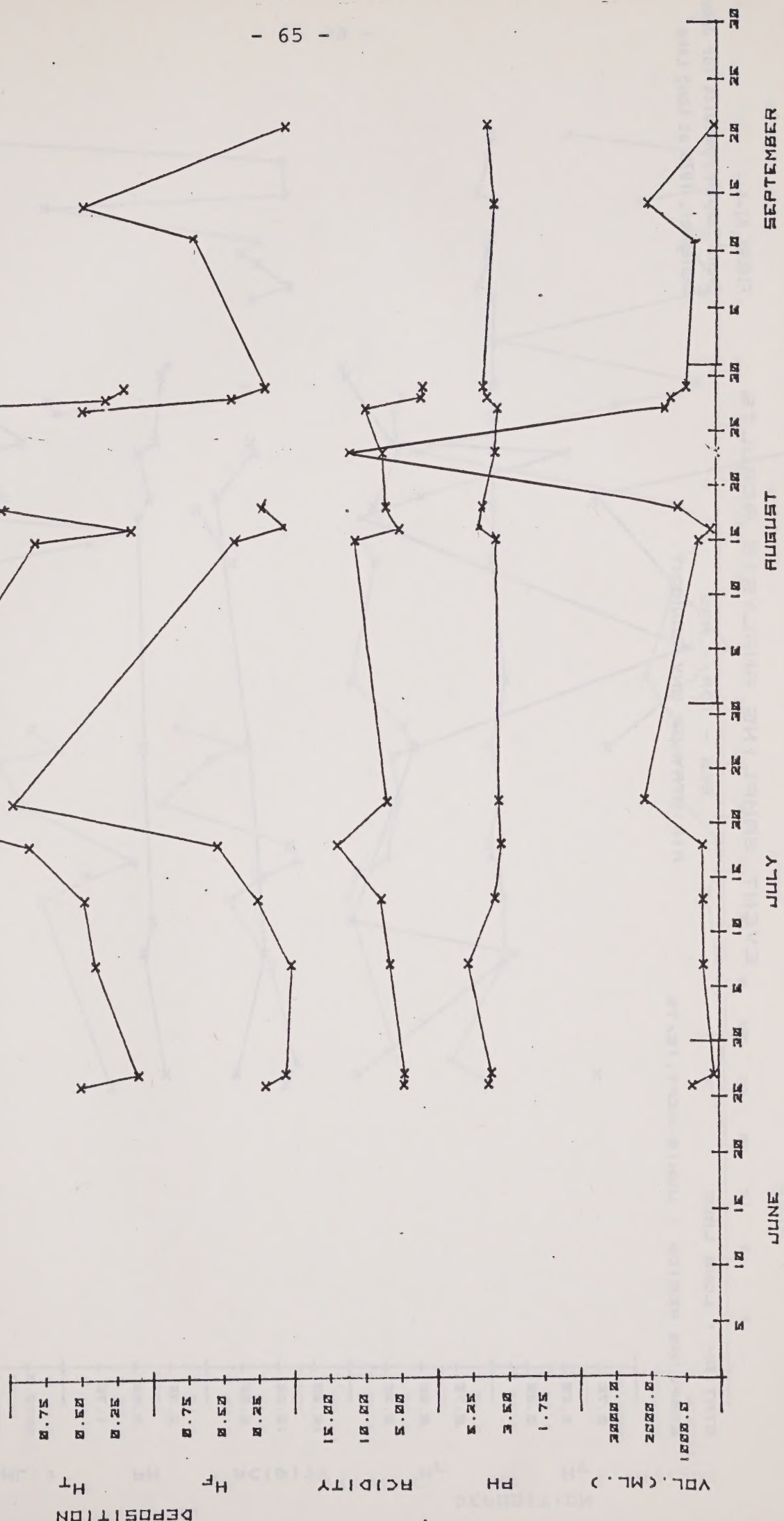


FIGURE A1-4:

Event Sampling Results for June -
September, 1978 at Long Lake

EVENT SAMPLING ANALYSIS RESULTS

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION: LONG LAKE
SAMPLING PERIOD: JUN 15 - SEPT. 15, 1978

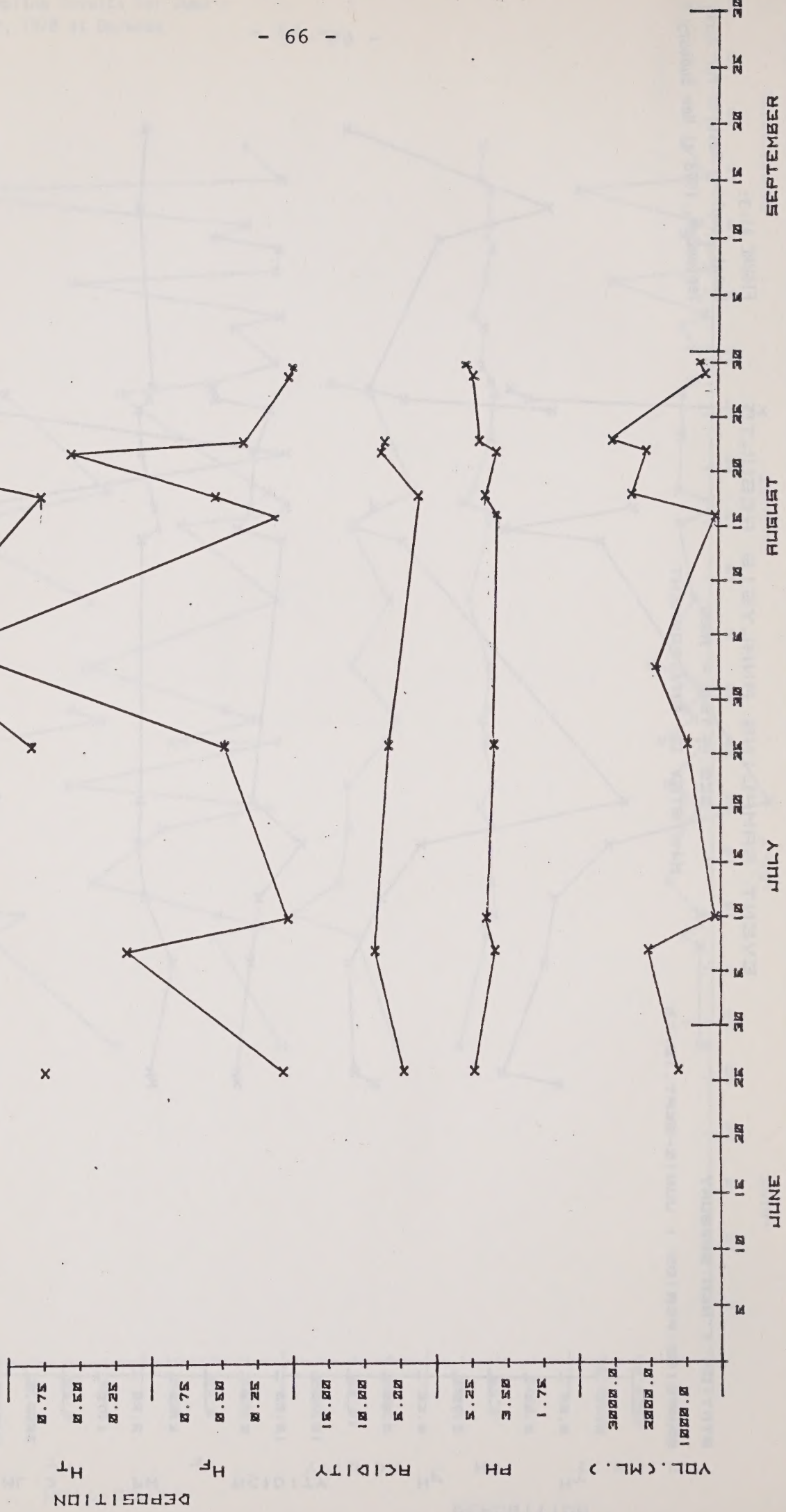


FIGURE A1-5:

Event Sampling Results for June -
September, 1978 at Wanup

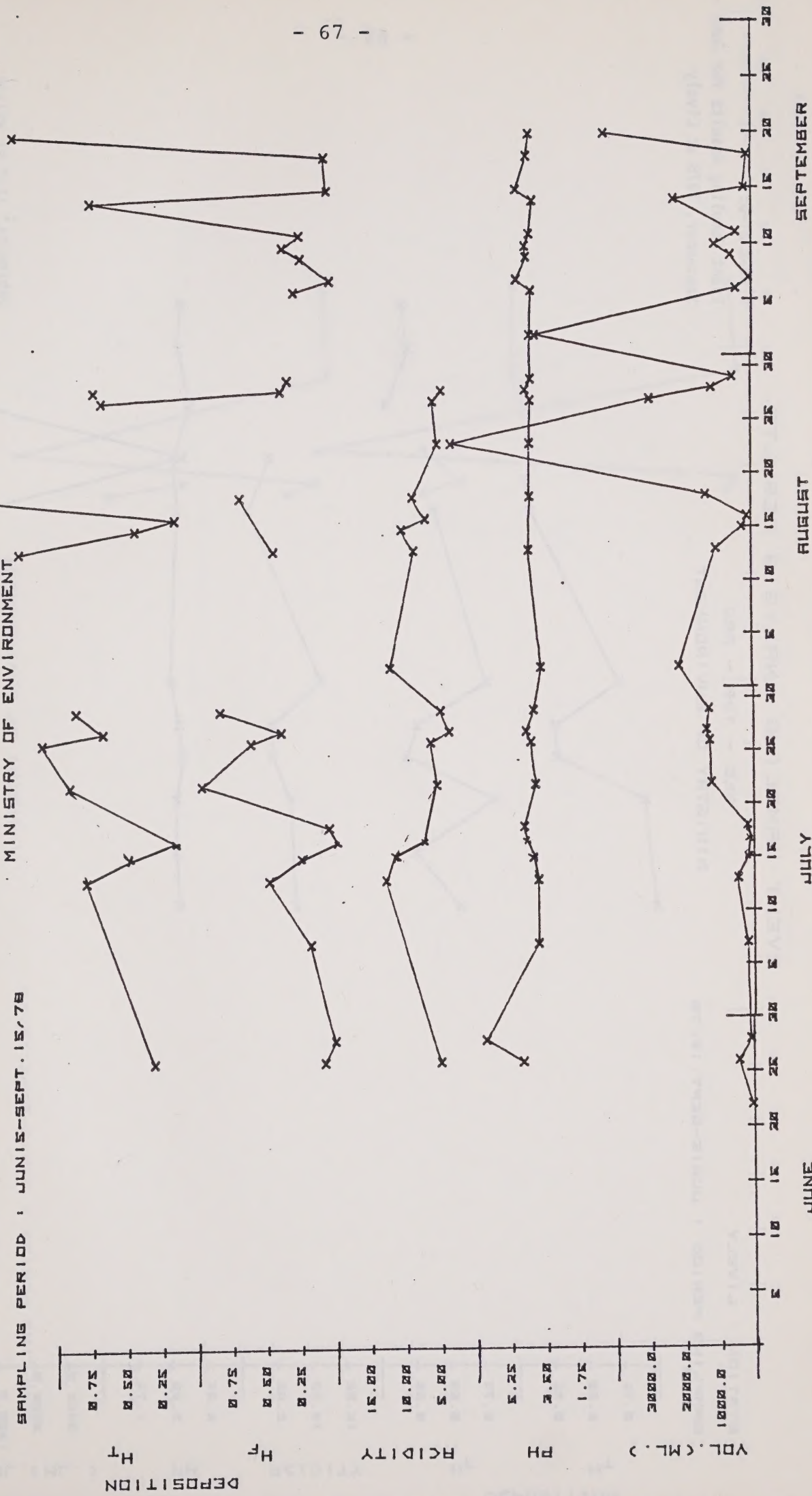
EVENT SAMPLING ANALYSIS RESULTS

STATION : WANUP

SAMPLING PERIOD : JUNIS-SEPT. 15, 78

SES - TDA - ARB

MINISTRY OF ENVIRONMENT



EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-6:

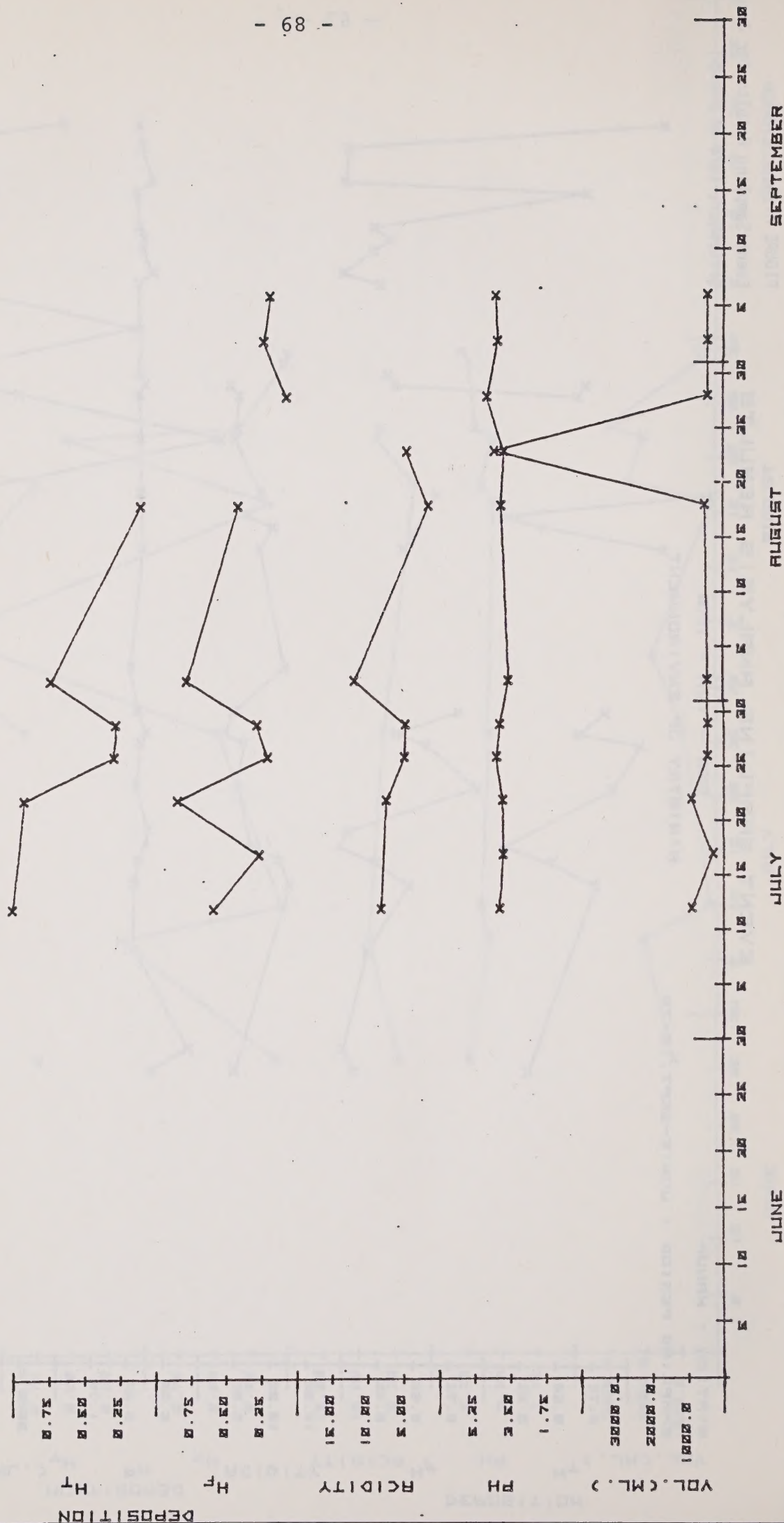
STATION : LIVELY

SES - TDR - ARB

SAMPLING PERIOD : JUN15-SEPT.15/78

MINISTRY OF ENVIRONMENT

Event Sampling Results for June -
September, 1978 at Lively



EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-7:

Event Sampling Results for June -
September, 1978 at Azilda

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : AZILDA

SAMPLING PERIOD : JUN15-SEPT.15,78

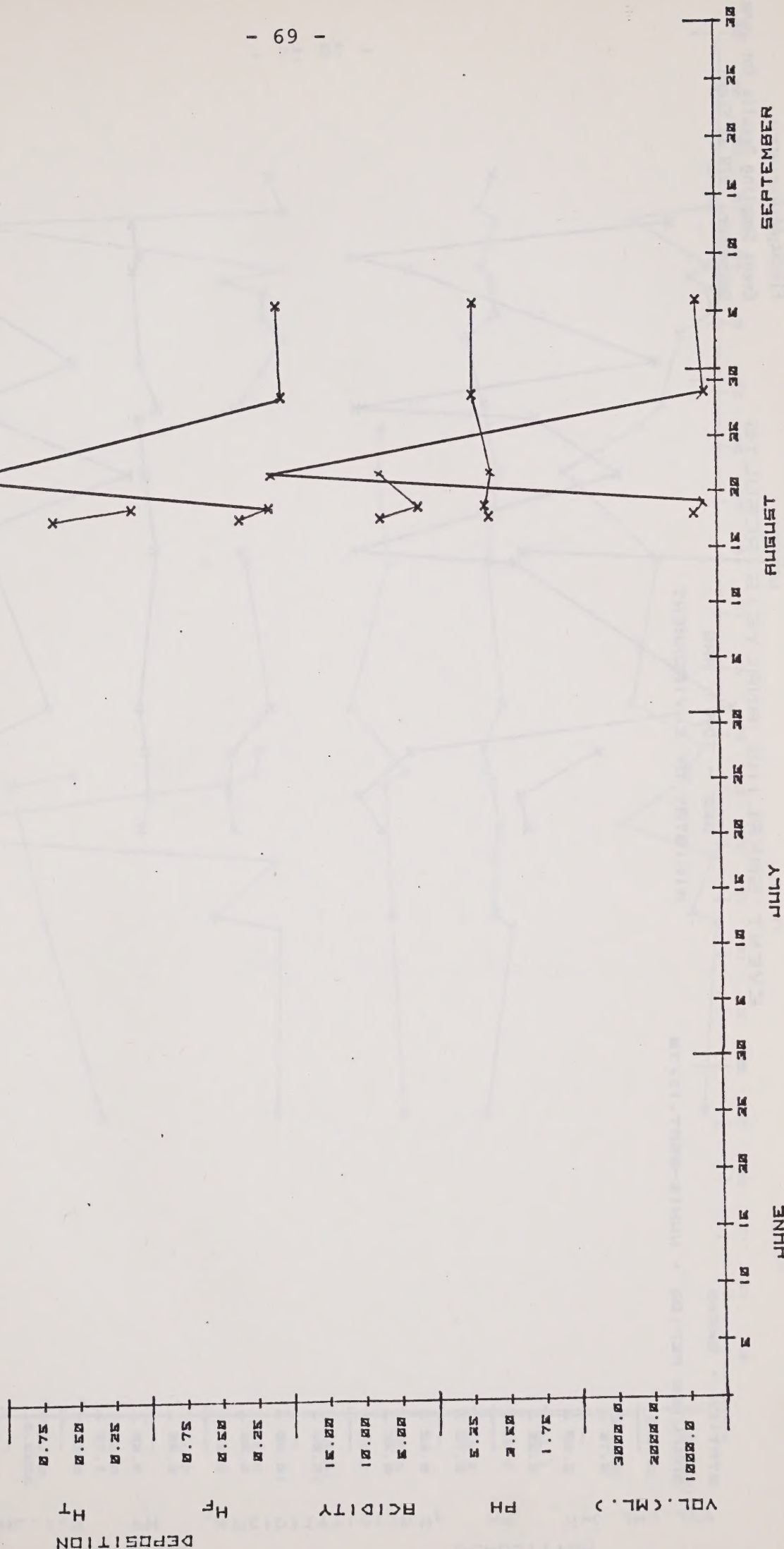


FIGURE A1-8:

Event Sampling Results for June - September, 1978 at Skead

EVENT SAMPLING ANALYSIS RESULTS

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : SKEAD
SAMPLING PERIOD : JUNIS-SEPT. 15, 78

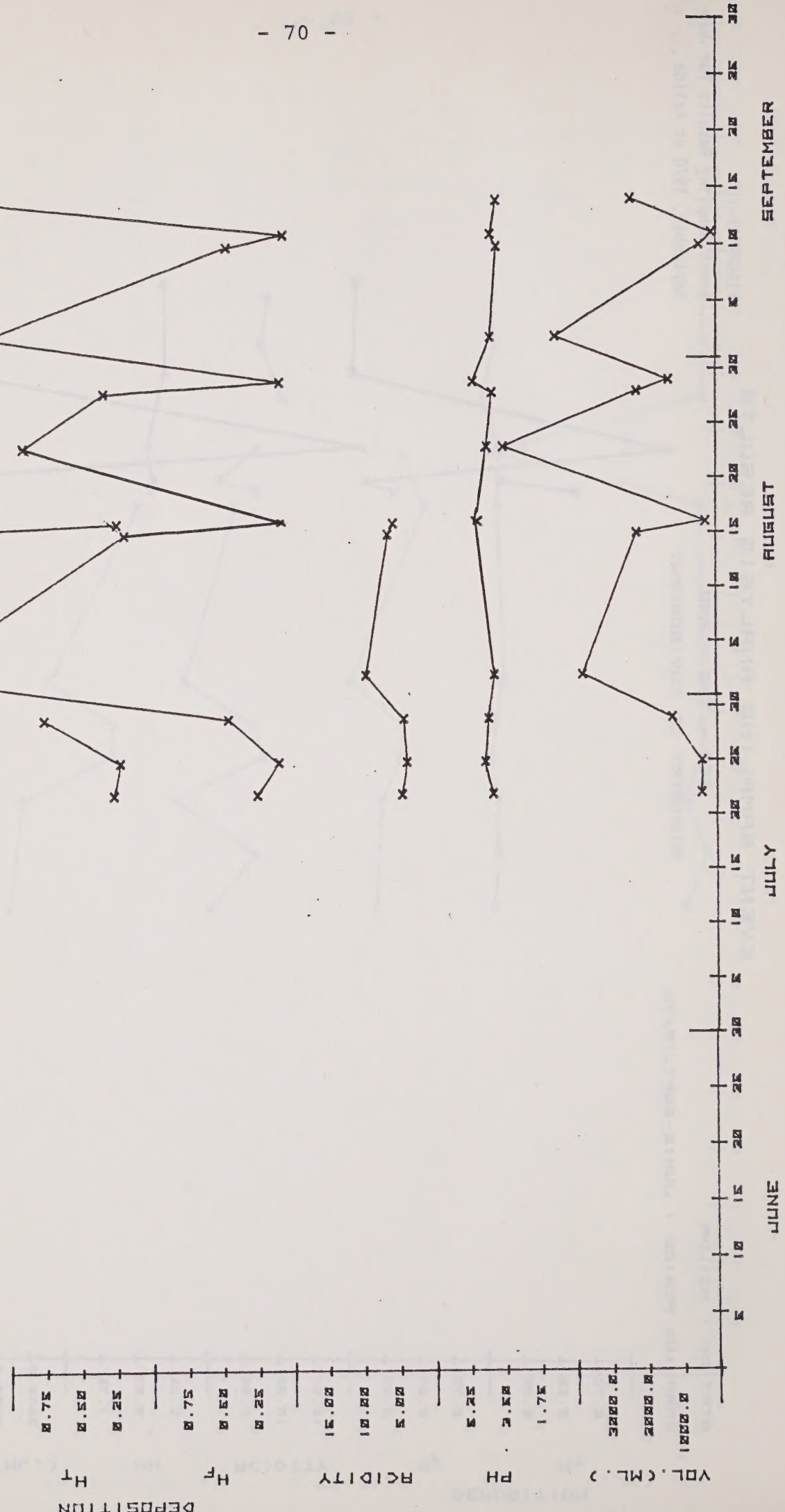


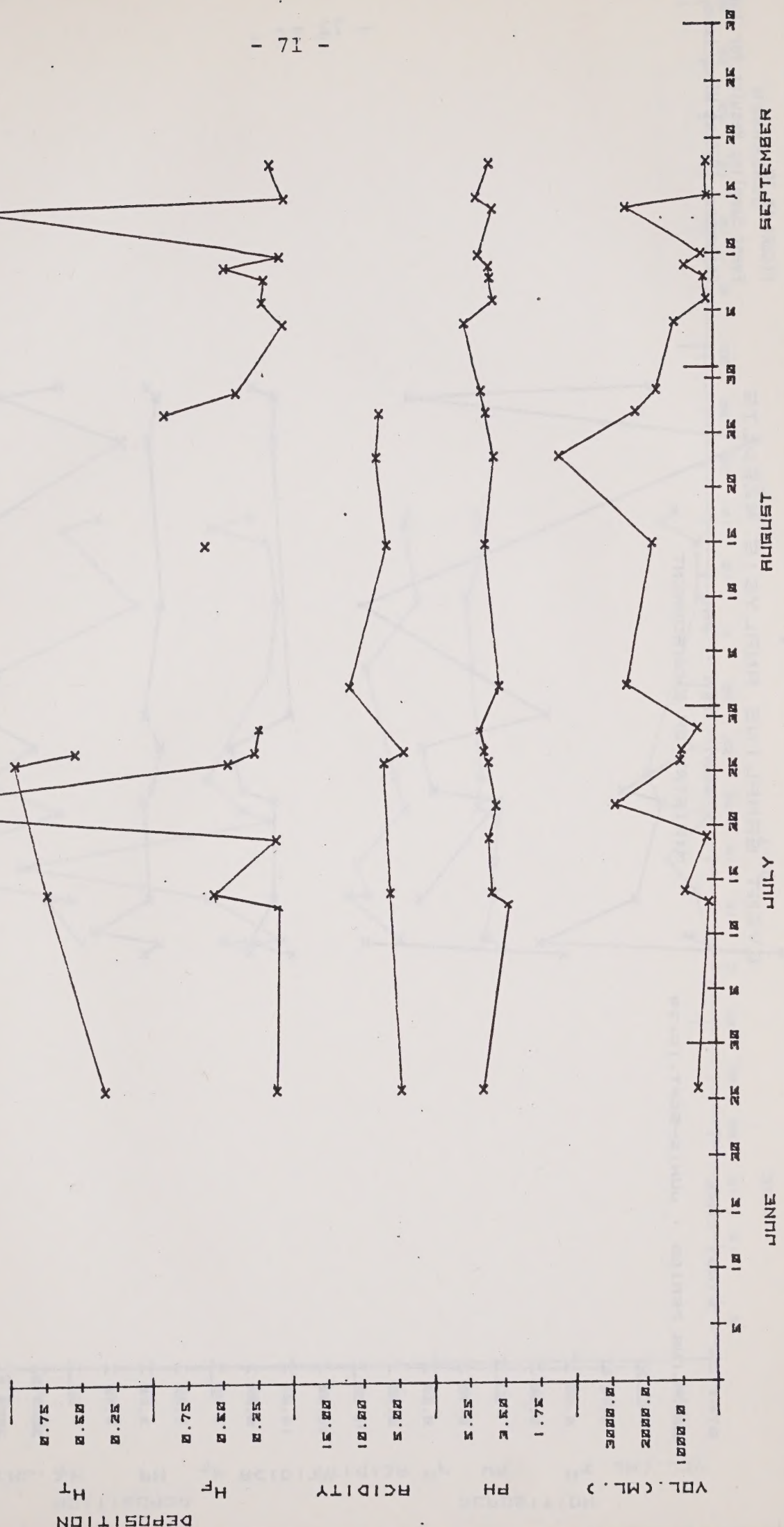
FIGURE A1-9:

Event Sampling Results for June - September, 1978 at McCharles Lake

EVENT SAMPLING ANALYSIS RESULTS

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : MCCHARLES LAKE
SAMPLING PERIOD : JUNIS-SEPT. 15, 78



SEPTEMBER

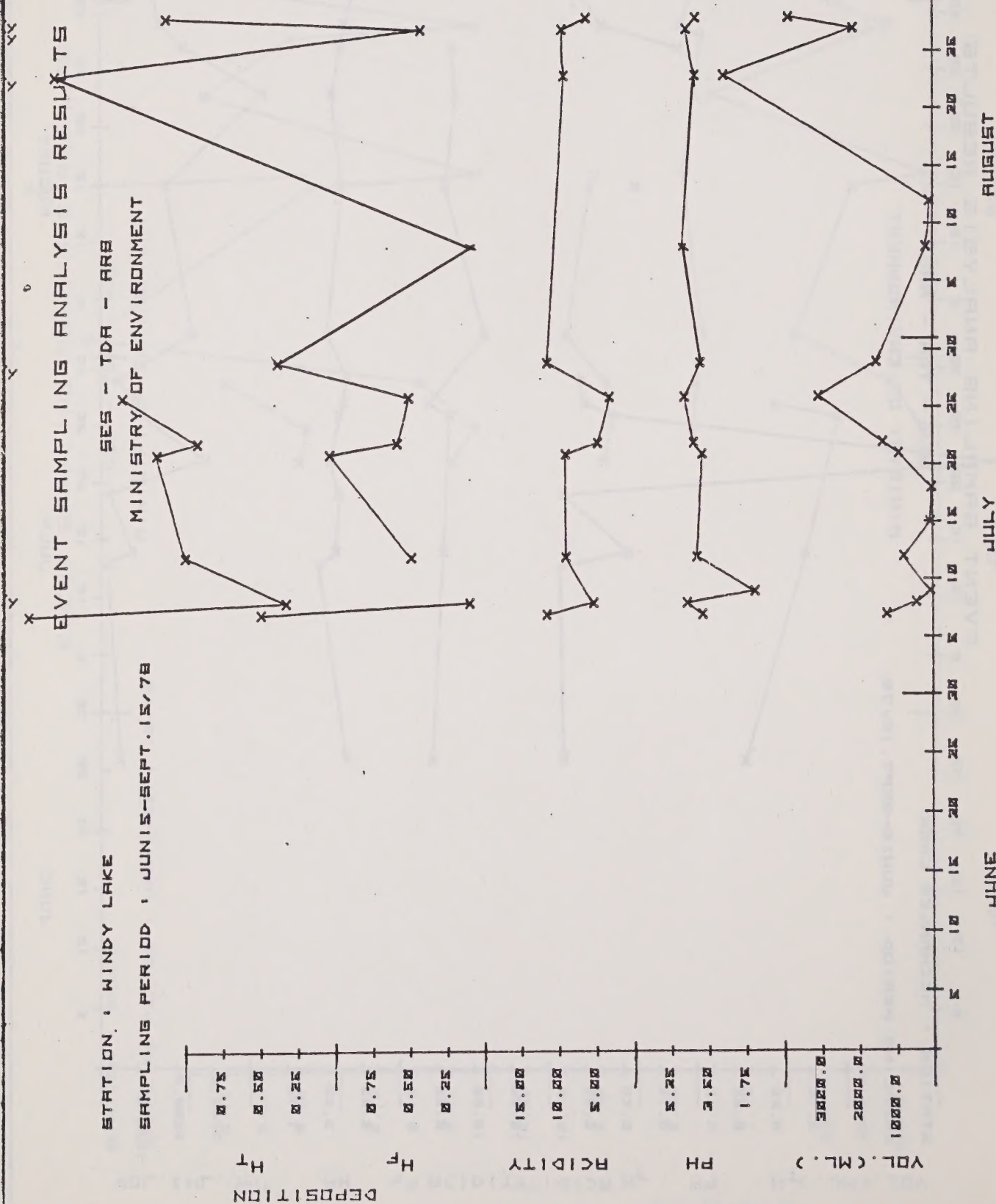
AUGUST

JULY

JUNE

FIGURE A1-10:

Event Sampling Results for June
September, 1978 at Windy Lake



EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-11:

Event Sampling Results for June - September, 1978 at Lake Wanapatei

STATION : LAKE WANAPATEI
SAMPLING PERIOD : JUN15-SEPT.15,78

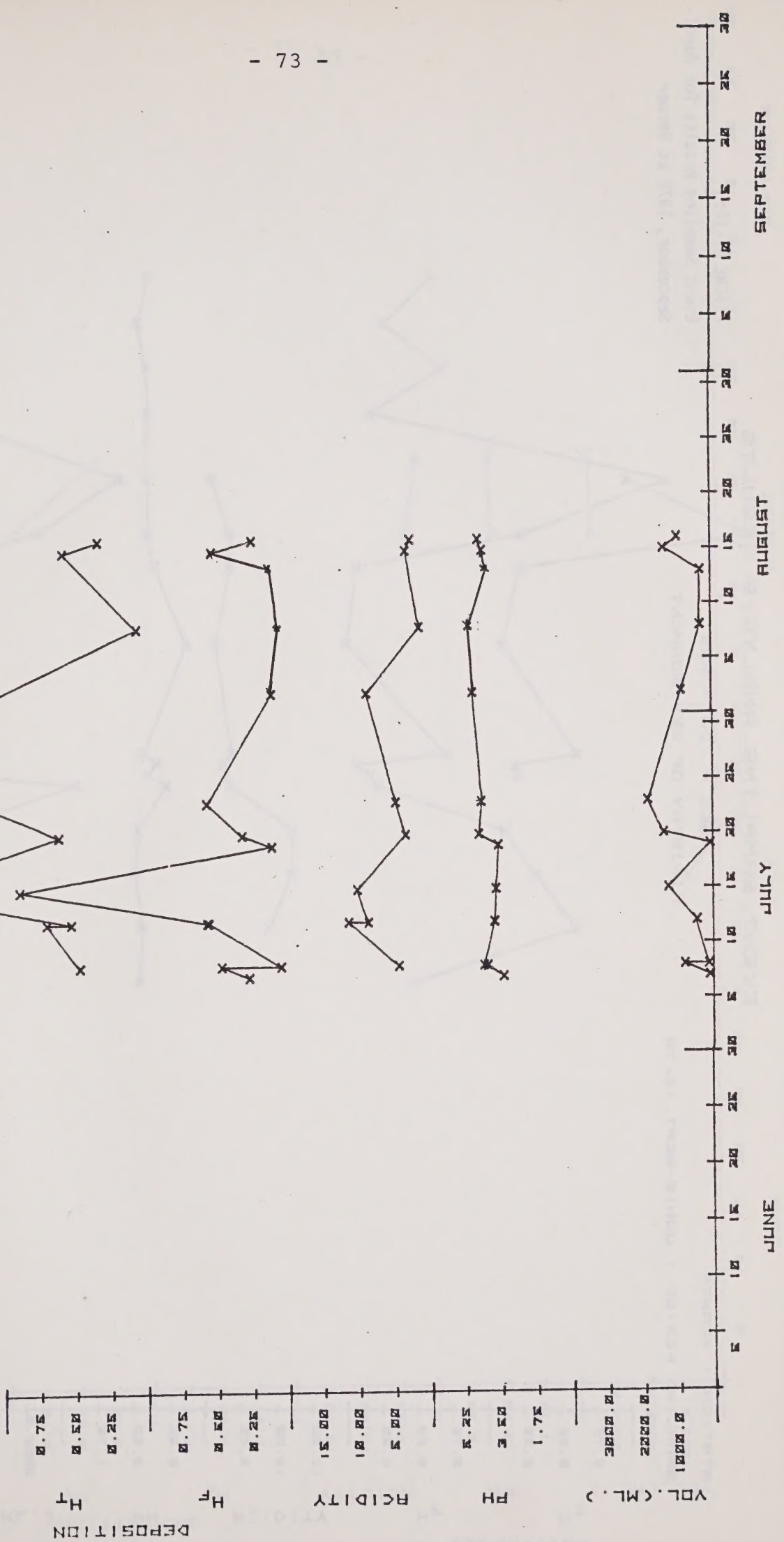


FIGURE A1-12:

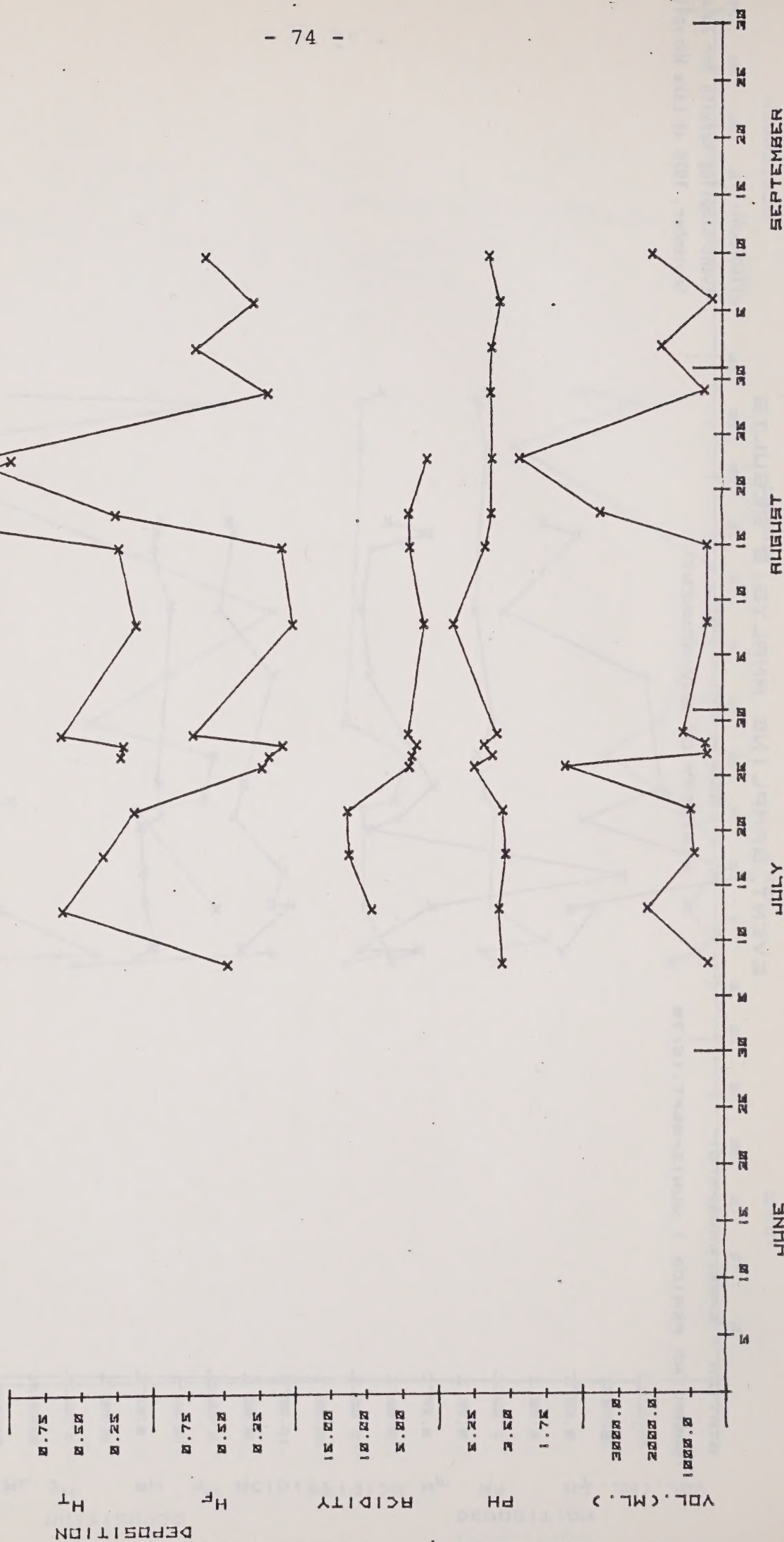
Event Sampling Results for June -
September, 1978 at Verner

EVENT-SAMPLING ANALYSIS RESULTS

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : VERNER

SAMPLING PERIOD : JUN15-SEPT.15/78



EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-13:

STATION : NORTH BAY

SES - TDA - ARB

MINISTRY OF ENVIRONMENT

SAMPLING PERIOD : JUN15-SEPT.15,78

Event Sampling Results for June -
September, 1978 at North Bay

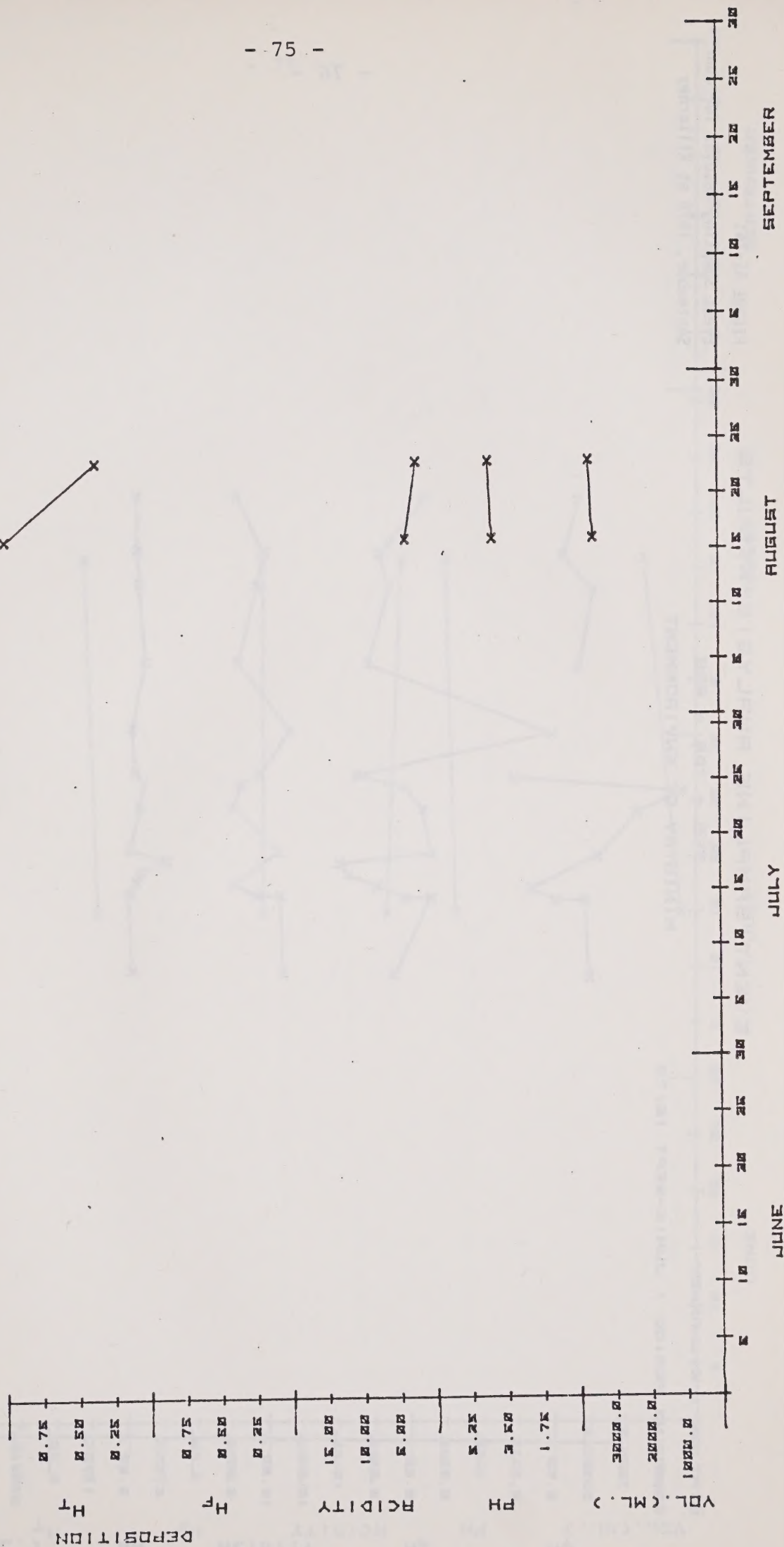


FIGURE A1-14:

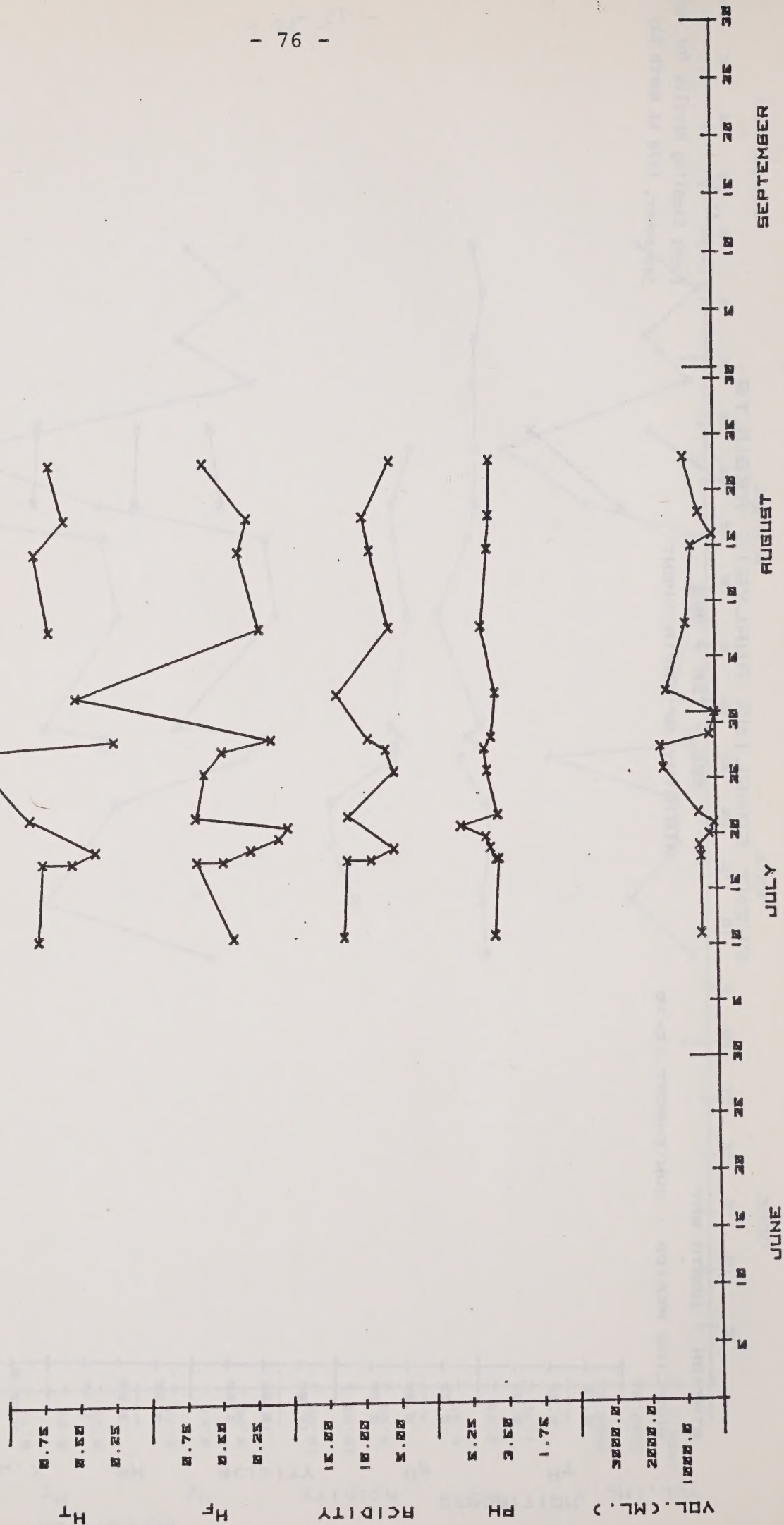
Event Sampling Results for June -
September, 1978 at Killarney

EVENT SAMPLING ANALYSIS RESULTS

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : KILLARNEY

SAMPLING PERIOD : JUNE-SEPT. 1978



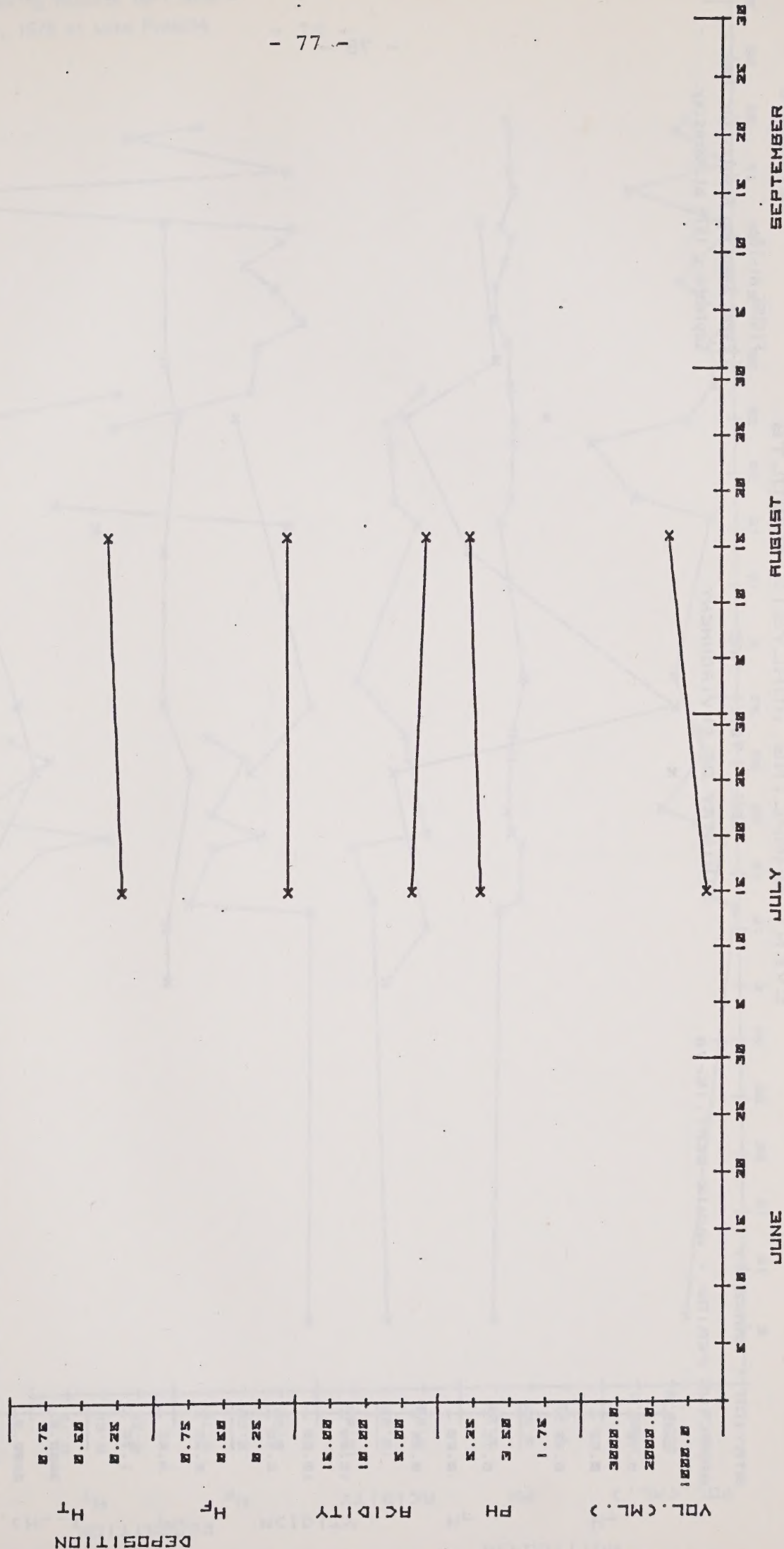
EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-15:

Event Sampling Results for June -
September 1978 at Charleton Stn.

SES - TDR - ARB
MINISTRY OF ENVIRONMENT

STATION : CHARLETON STN.
SAMPLING PERIOD : JUN15-SEPT.15/78



EVENT SAMPLING ANALYSIS RESULTS

STATION: MARKSTAY

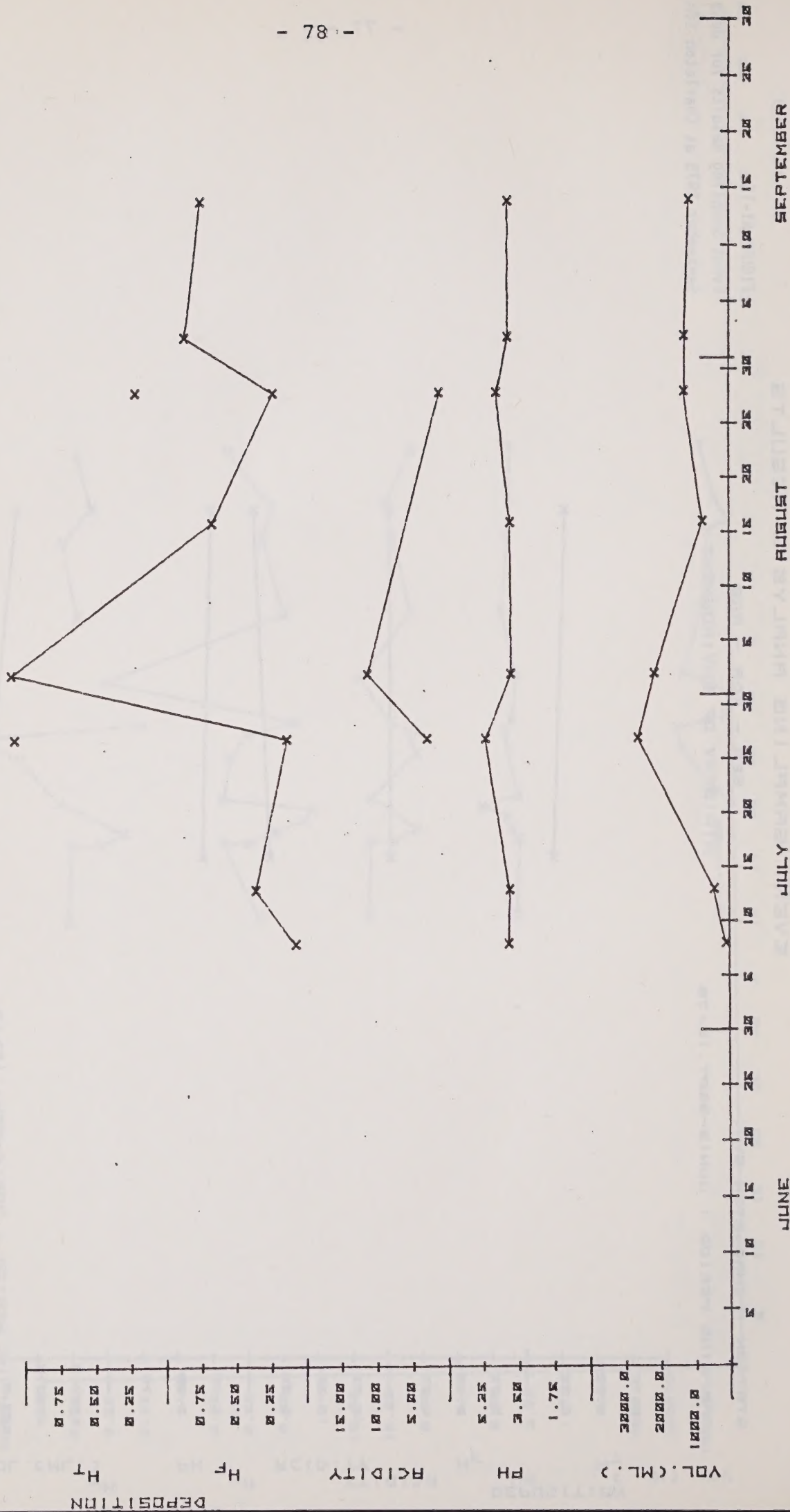
SES - TDA - ARB

SAMPLING PERIOD: JUNIS-SEPT.15,78

MINISTRY OF ENVIRONMENT

FIGURE A1-16:

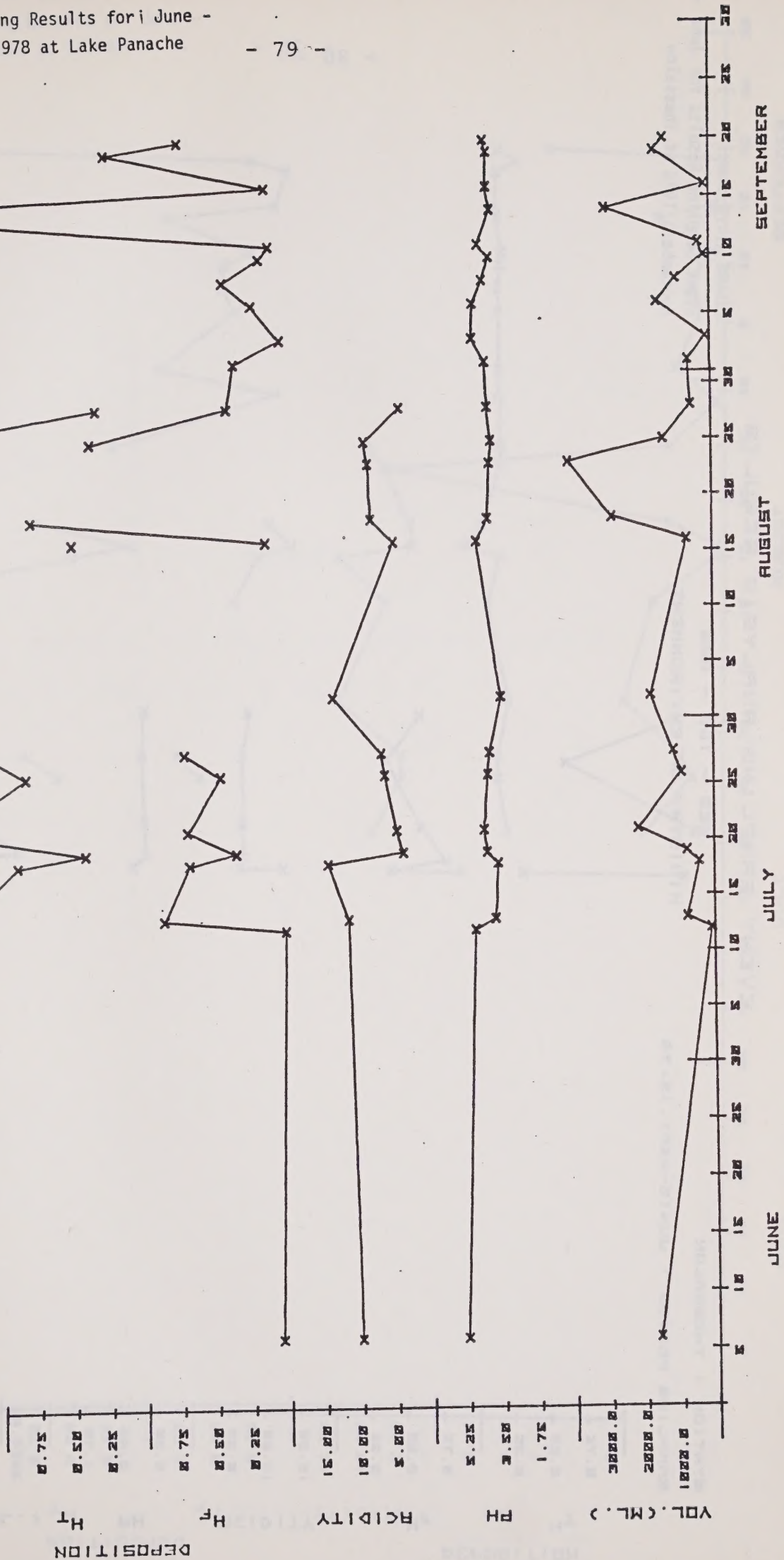
Event Sampling Results for June -
September, 1978 at Markstay



EVENT SAMPLING ANALYSIS RESULTS

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : LAKE PANACHE
SAMPLING PERIOD : JUNE-SEPT. 1978



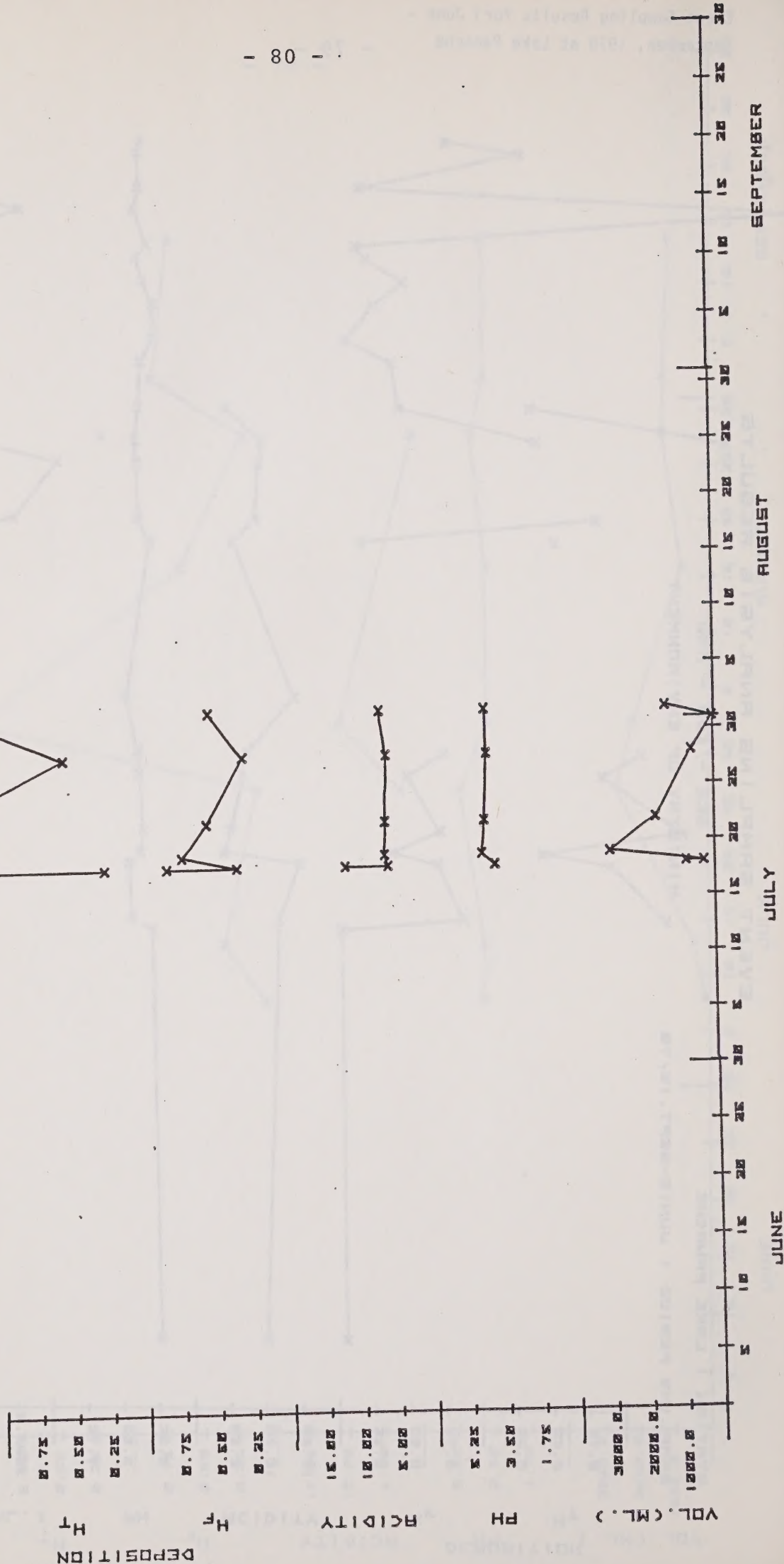
EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-18:

Event Sampling Results for June - September, 1978 at Thessalon

SES - TDA - ARS
MINISTRY OF ENVIRONMENT

STATION : THESSALON
SAMPLING PERIOD : JUN15-SEPT.15,78



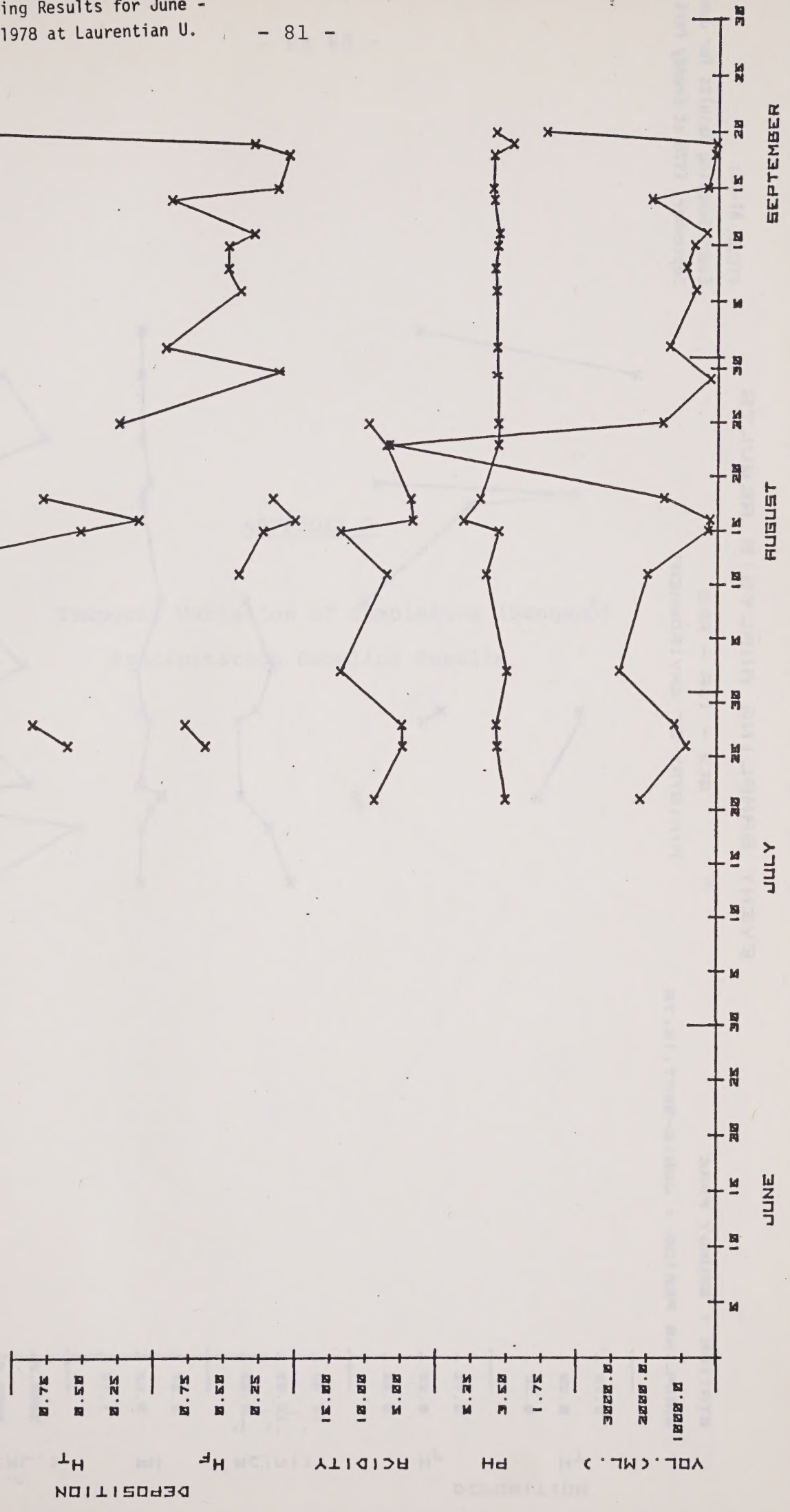
EVENT SAMPLING ANALYSIS RESULTS

SES - TDA - ARB

MINISTRY OF ENVIRONMENT

STATION : LAURENTIAN U.

SAMPLING PERIOD : JUNIS-SEPT. 15-78



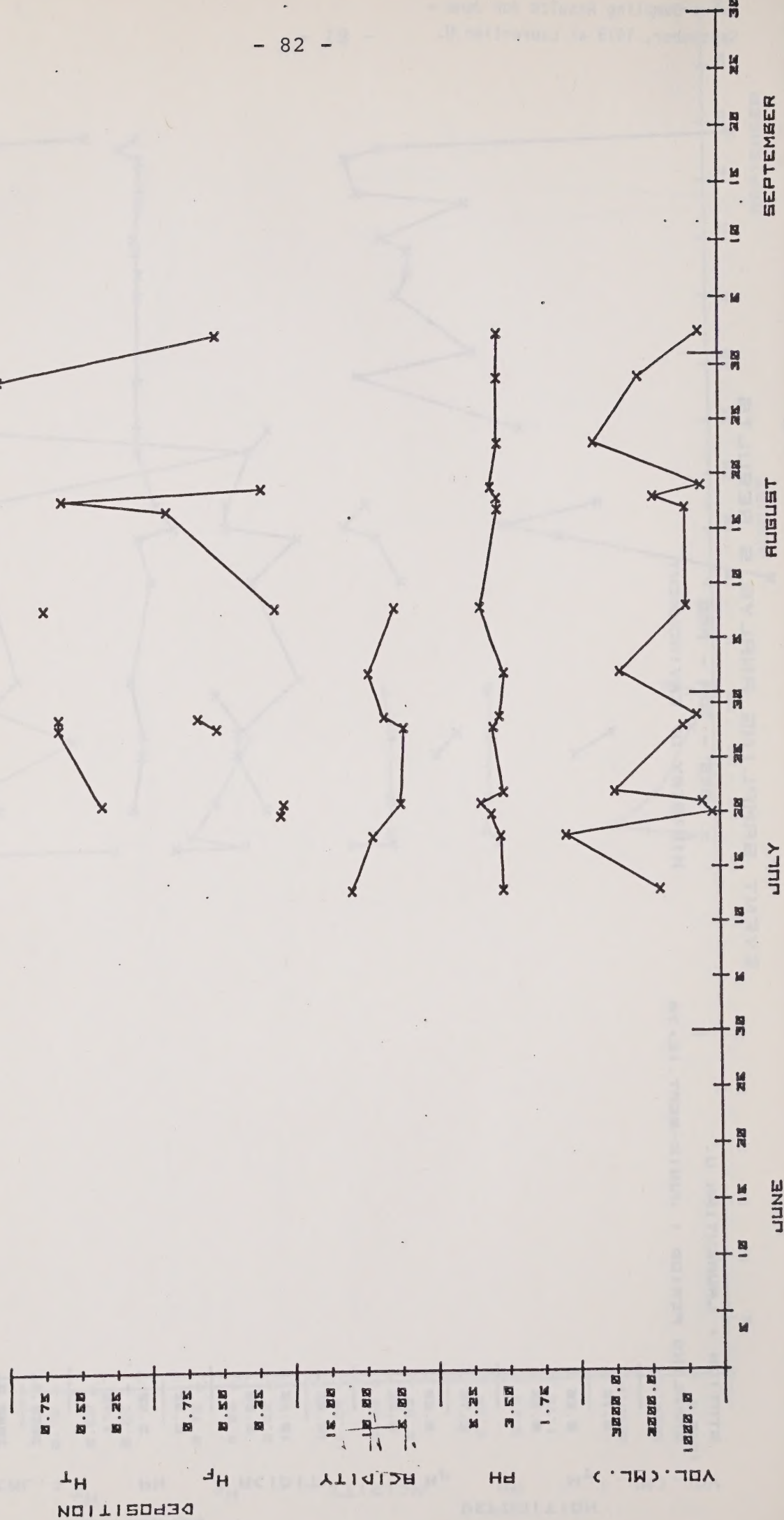
EVENT SAMPLING ANALYSIS RESULTS

FIGURE A1-20:
Event Sampling Results for June
September, 1978 at Grundy Park

STATION : GRUNDY PARK
SAMPLING PERIOD : JUN15-SEPT.15,78

X SES - TDA - ARB

MINISTRY OF ENVIRONMENT



APPENDIX 2

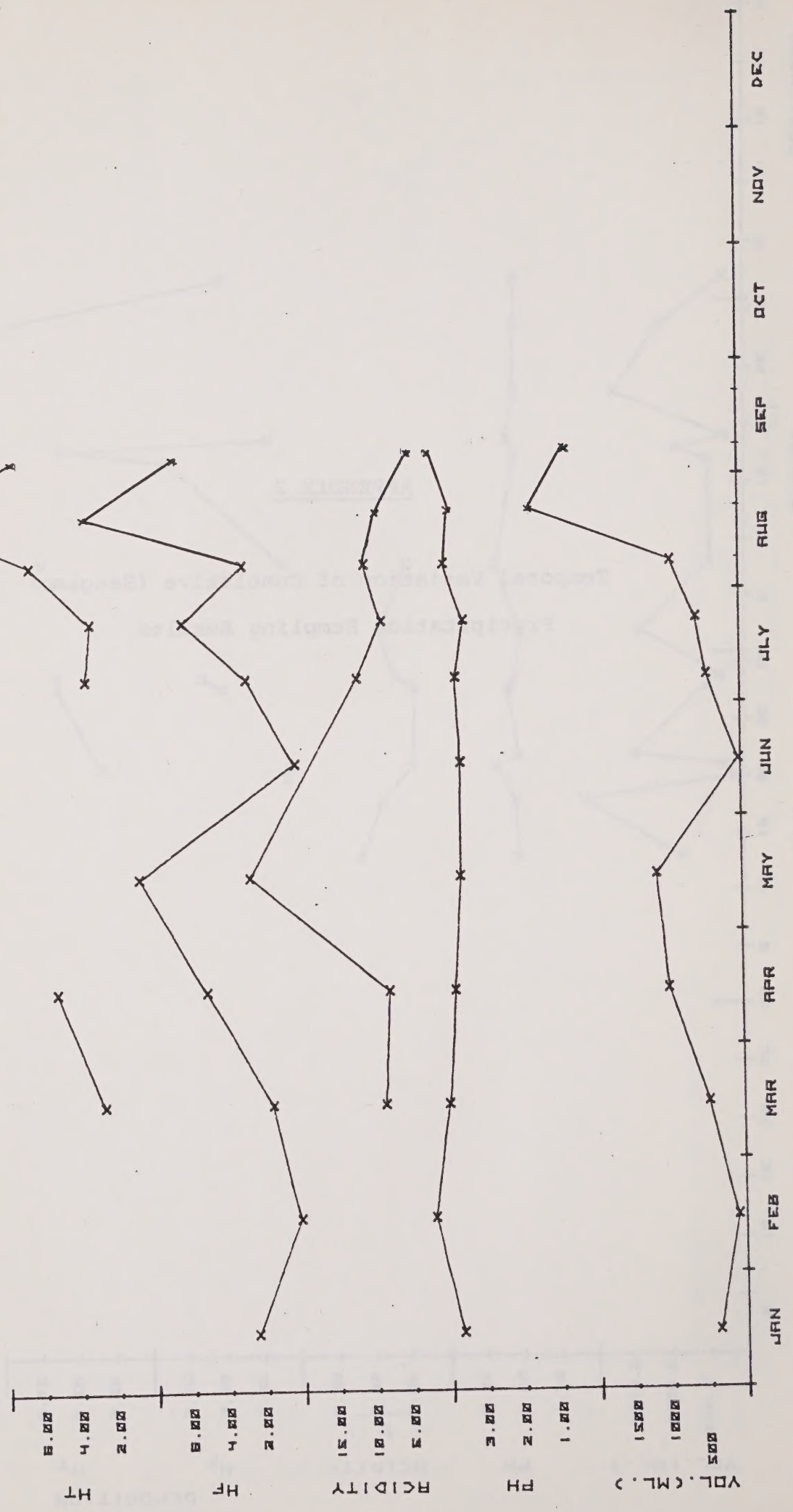
Temporal Variation of Cumulative (Sangamo)
Precipitation Sampling Results

MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-1:
Monthly (Sangamo) Sampling Results
for 1978 at Burwash

SES - TDA - ARS
MINISTRY OF ENVIRONMENT

STATION : BURWASH
SAMPLING PERIOD : JAN - DEC 1978



MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-2:

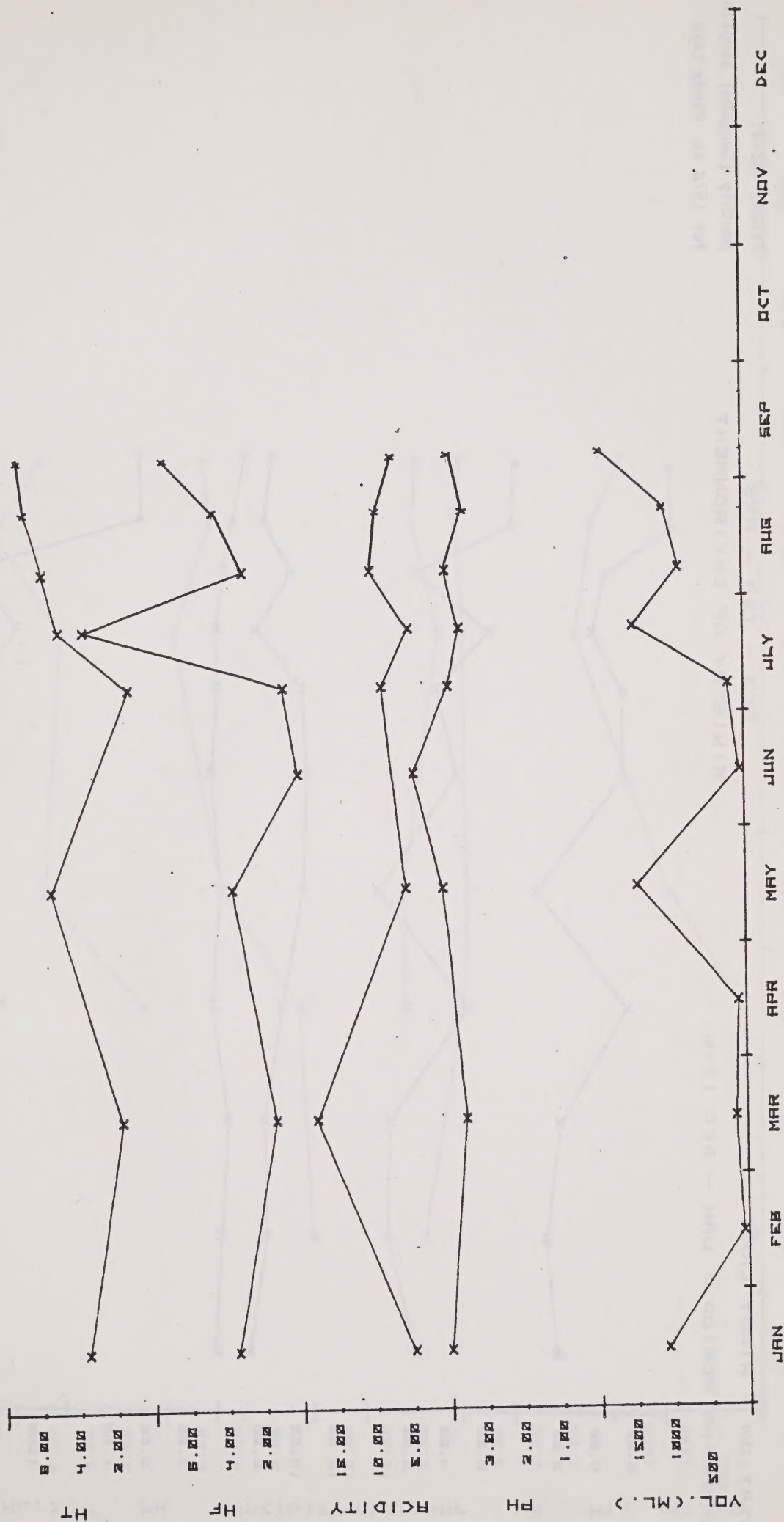
Monthly (Sangamo) Sampling Results
for 1978 at Panache

SES - TDA - ARS
MINISTRY OF ENVIRONMENT

STATION : PANACHE

SAMPLING PERIOD : JAN - DEC 1978

DEPOSITION (MG/M2)



MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-3:

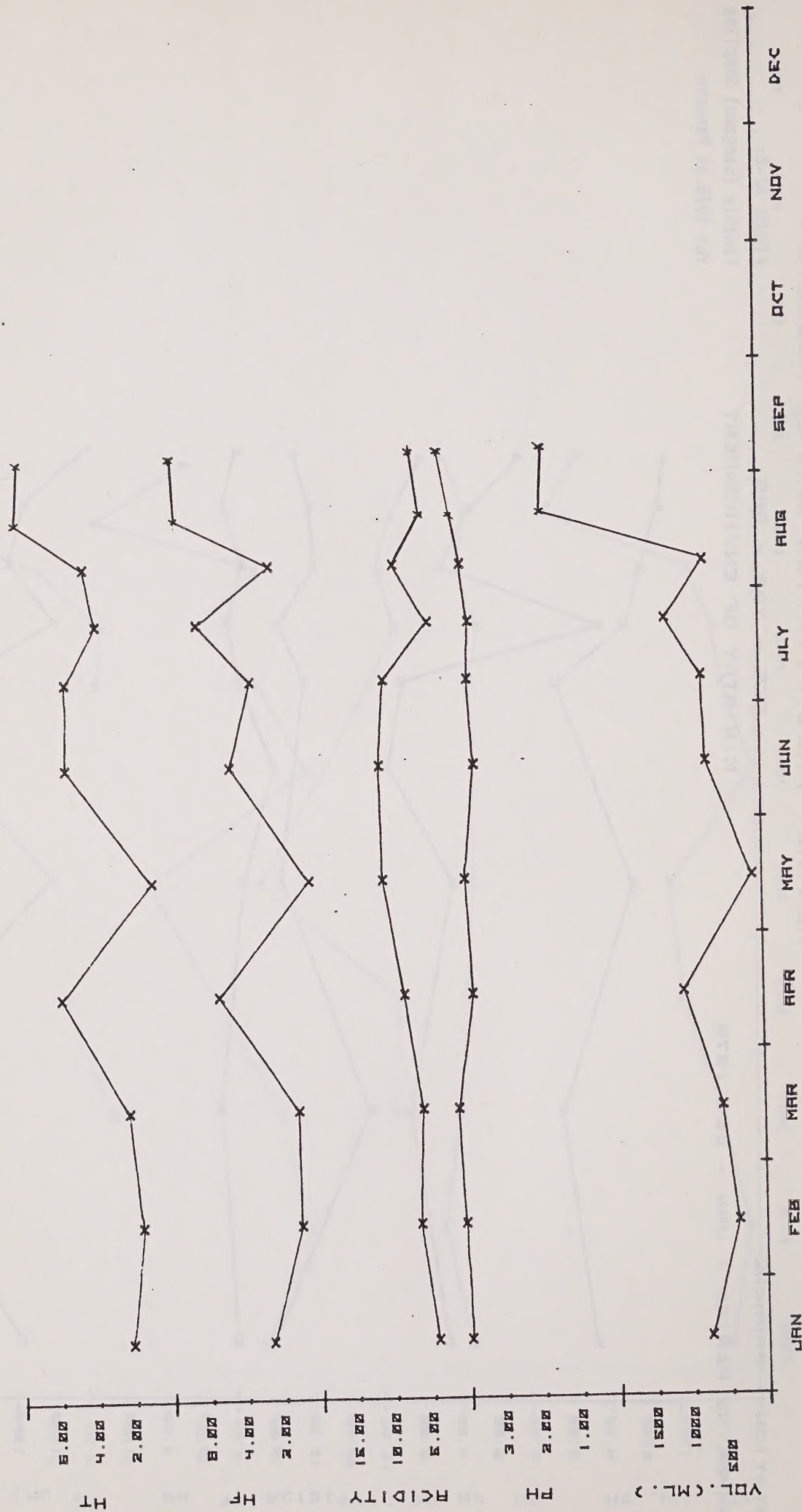
Monthly (Sangamo) Sampling Results
for 1978 at Windy Lake

SES - TDA - ARS
MINISTRY OF ENVIRONMENT

STATION : WINDY LAKE

SAMPLING PERIOD : JAN - DEC 1978

DEPOSITION (MG/M2)



MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-4:

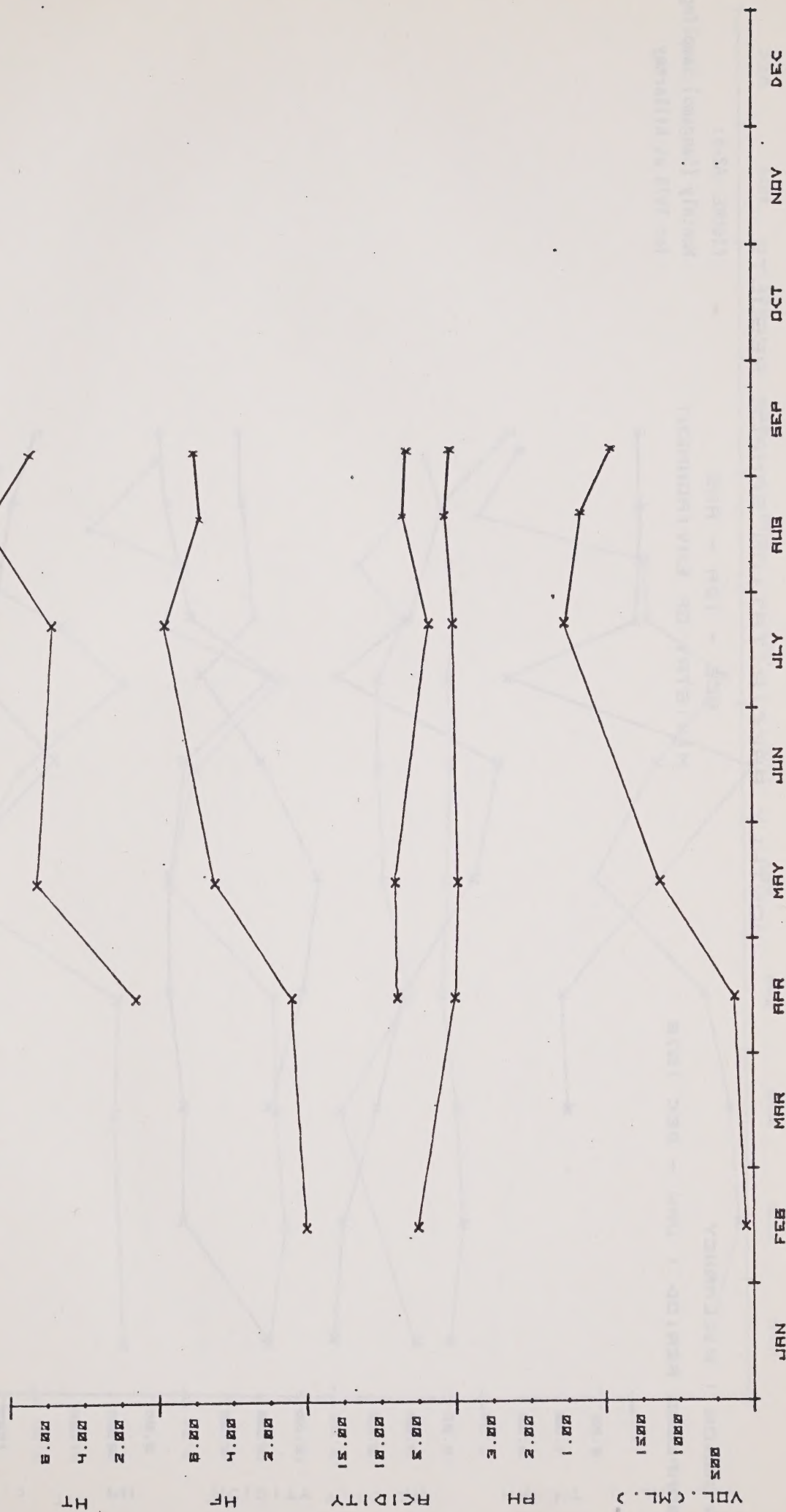
Monthly (Sangamo) Sampling Results
for 1978 at Hanmer

SES - TDA - ARS
MINISTRY OF ENVIRONMENT

STATION : HANMER

SAMPLING PERIOD : JAN - DEC 1978

DEPOSITION (MG/M2)

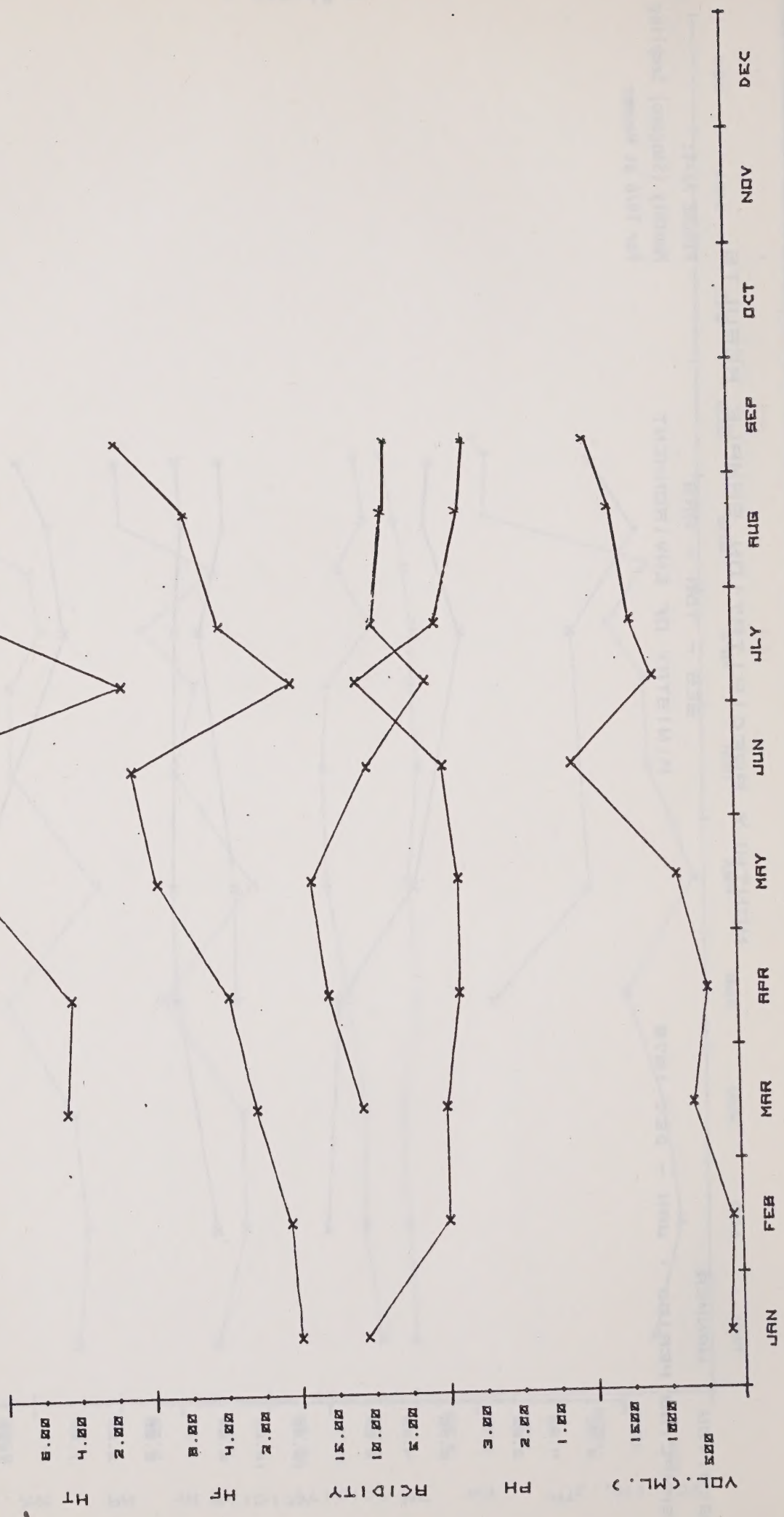


MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-5:
Monthly (Sangamo) Sampling Results
for 1978 at Killarney

SES - TDA - ARS
MINISTRY OF ENVIRONMENT

STATION : KILLARNEY
SAMPLING PERIOD : JAN - DEC 1978



MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-6:

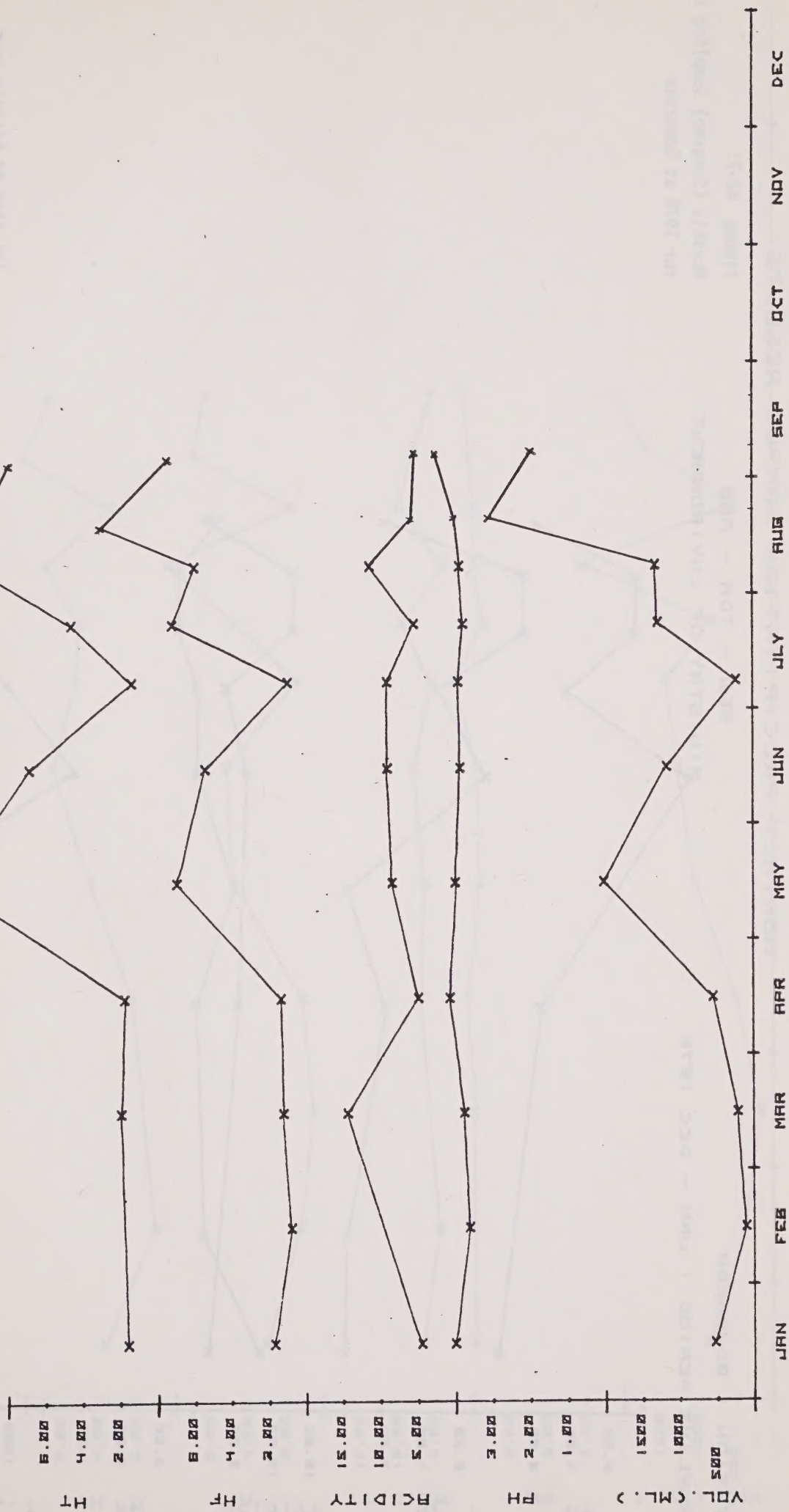
Monthly (Sangamo) Sampling Results
for 1978 at St. Charles

STATION : ST. CHARLES

SAMPLING PERIOD : JAN - DEC 1978

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

DEPOSITION (MG/M2)



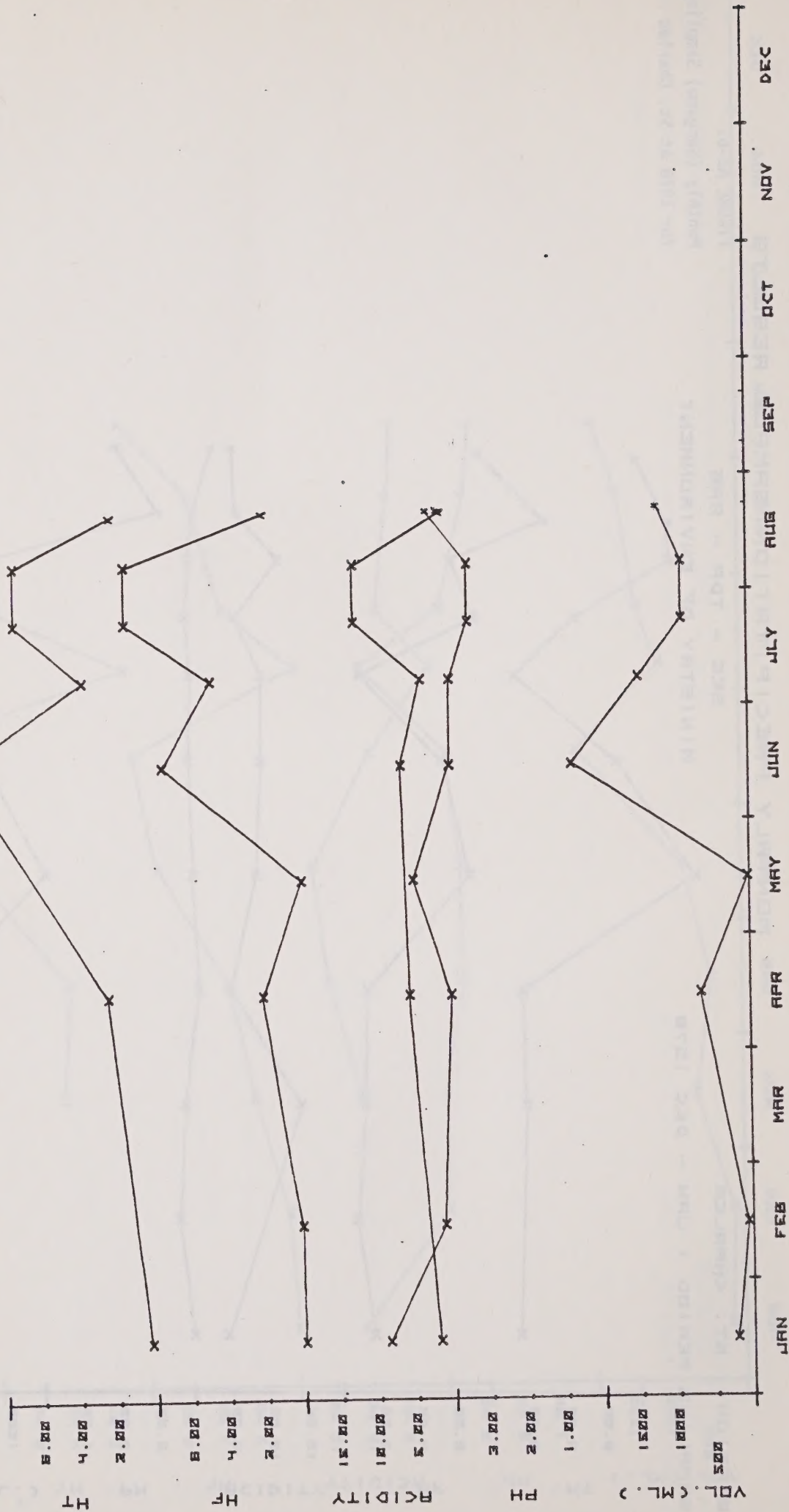
MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-7:
Monthly (Sangamo) Sampling Results
for 1978 at Gowganda

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : GOWGANDA

SAMPLING PERIOD : JAN - DEC 1978



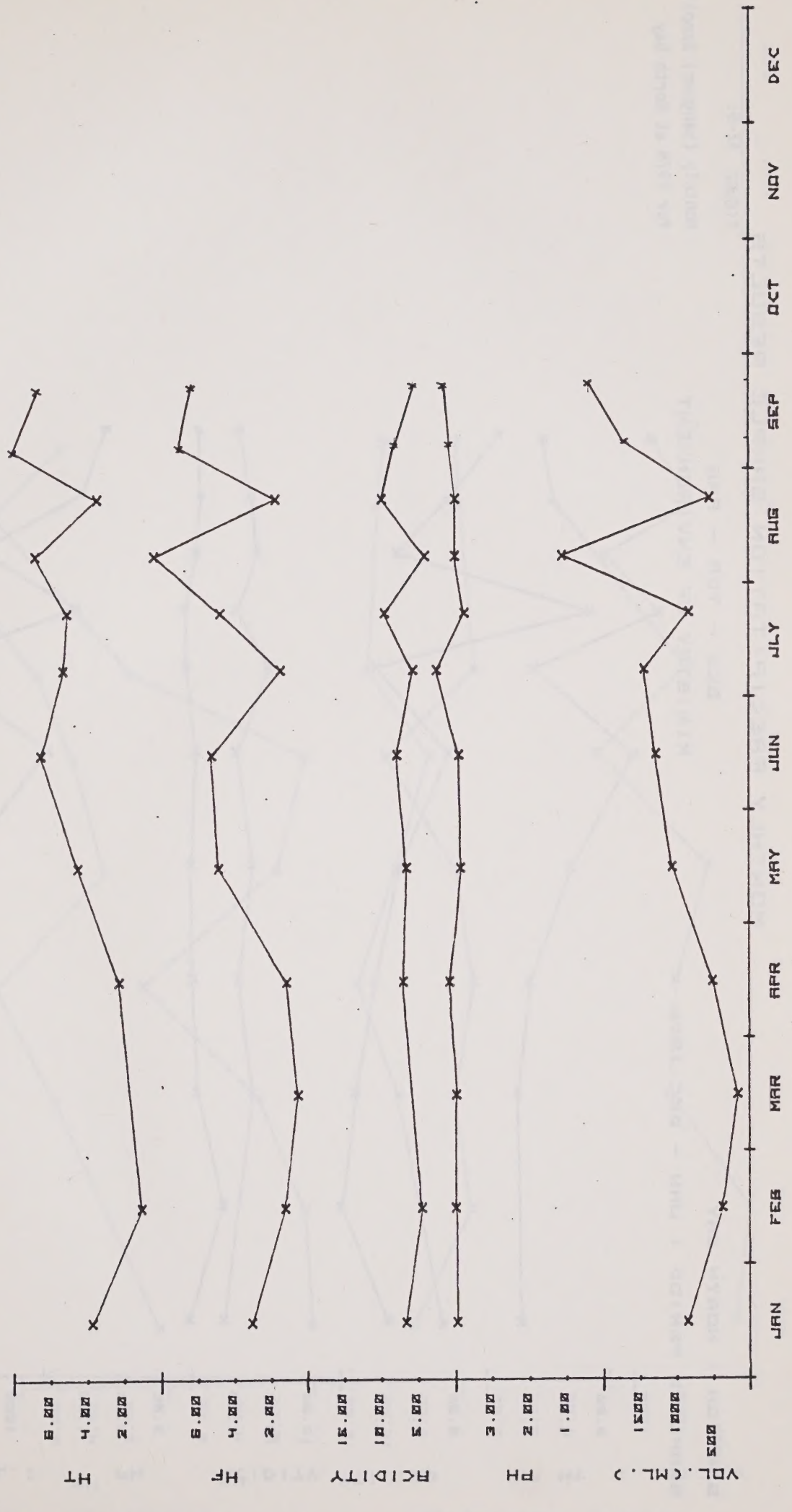
MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-8:

Monthly (Sangamo) Sampling Results
for 1978 at Elliott Lake

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : ELLIOTT LAKE
SAMPLING PERIOD : JAN - DEC 1978



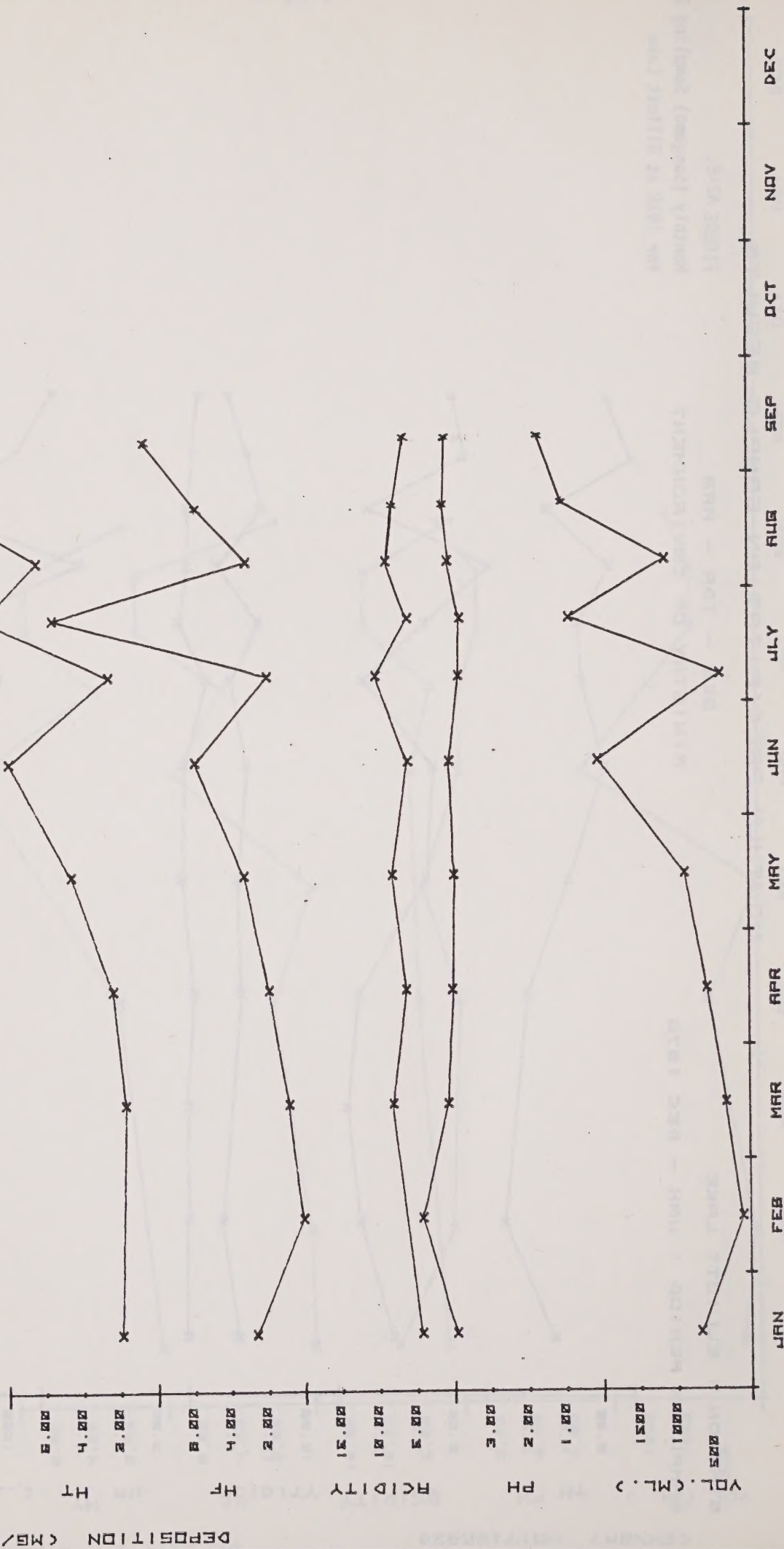
MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-9:

Monthly (Sangamo) Sampling Results
for 1978 at North Bay

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : NORTH BAY
SAMPLING PERIOD : JAN - DEC 1978

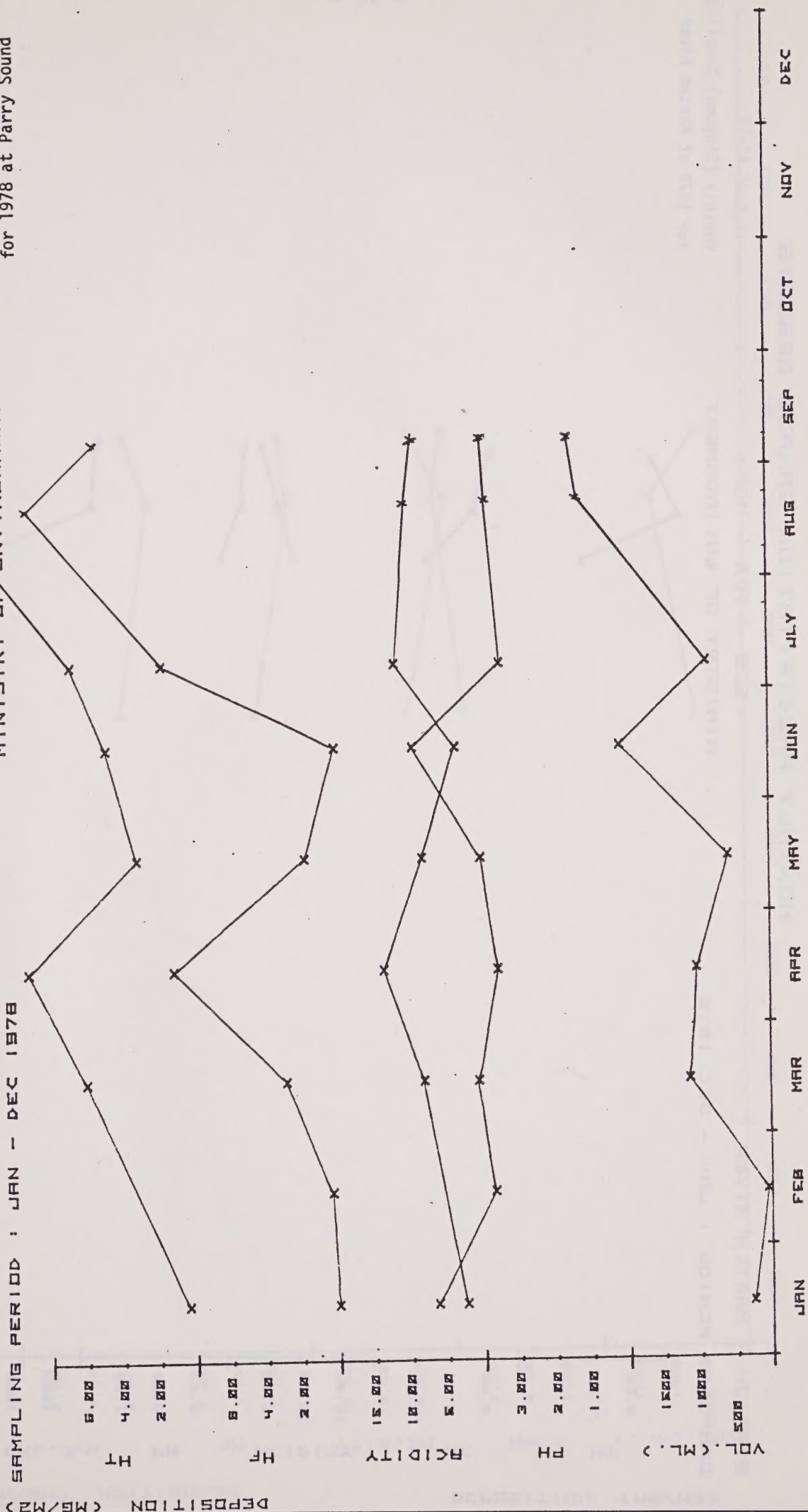


MONTHLY PRECIPITATION SAMPLE RESULTS
FIGURE A2-10:

Monthly (Sangamo) Sampling Results
for 1978 at Parry Sound

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : PARRY SOUND
SAMPLING PERIOD : JAN - DEC 1978

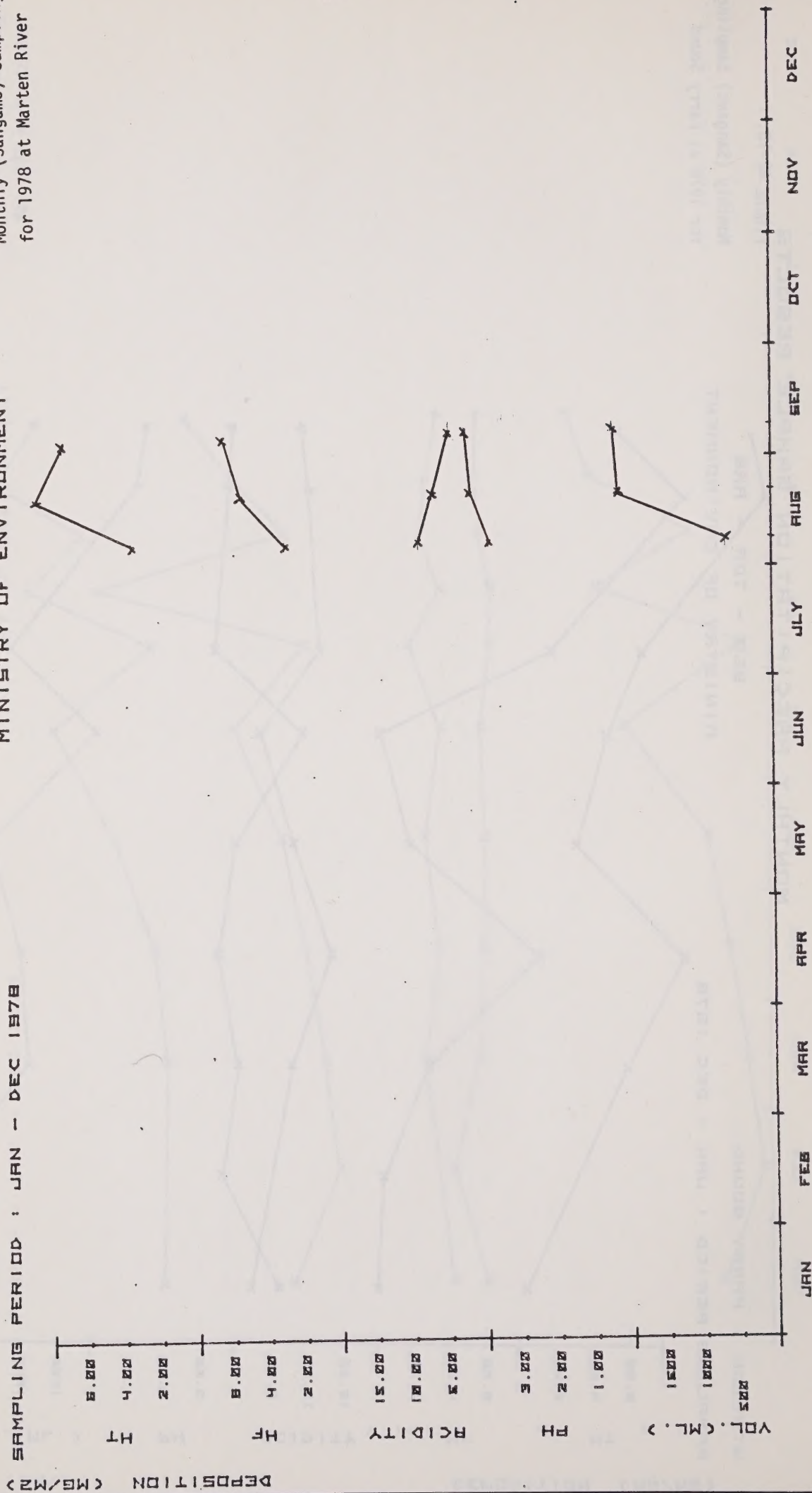


MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-11:
Monthly (Sangamo) Sampling Results
for 1978 at Marten River

SES - TDR - ARB
MINISTRY OF ENVIRONMENT

STATION : MARTEN RIVER
SAMPLING PERIOD : JAN - DEC 1978



MONTHLY PRECIPITATION SAMPLE RESULTS

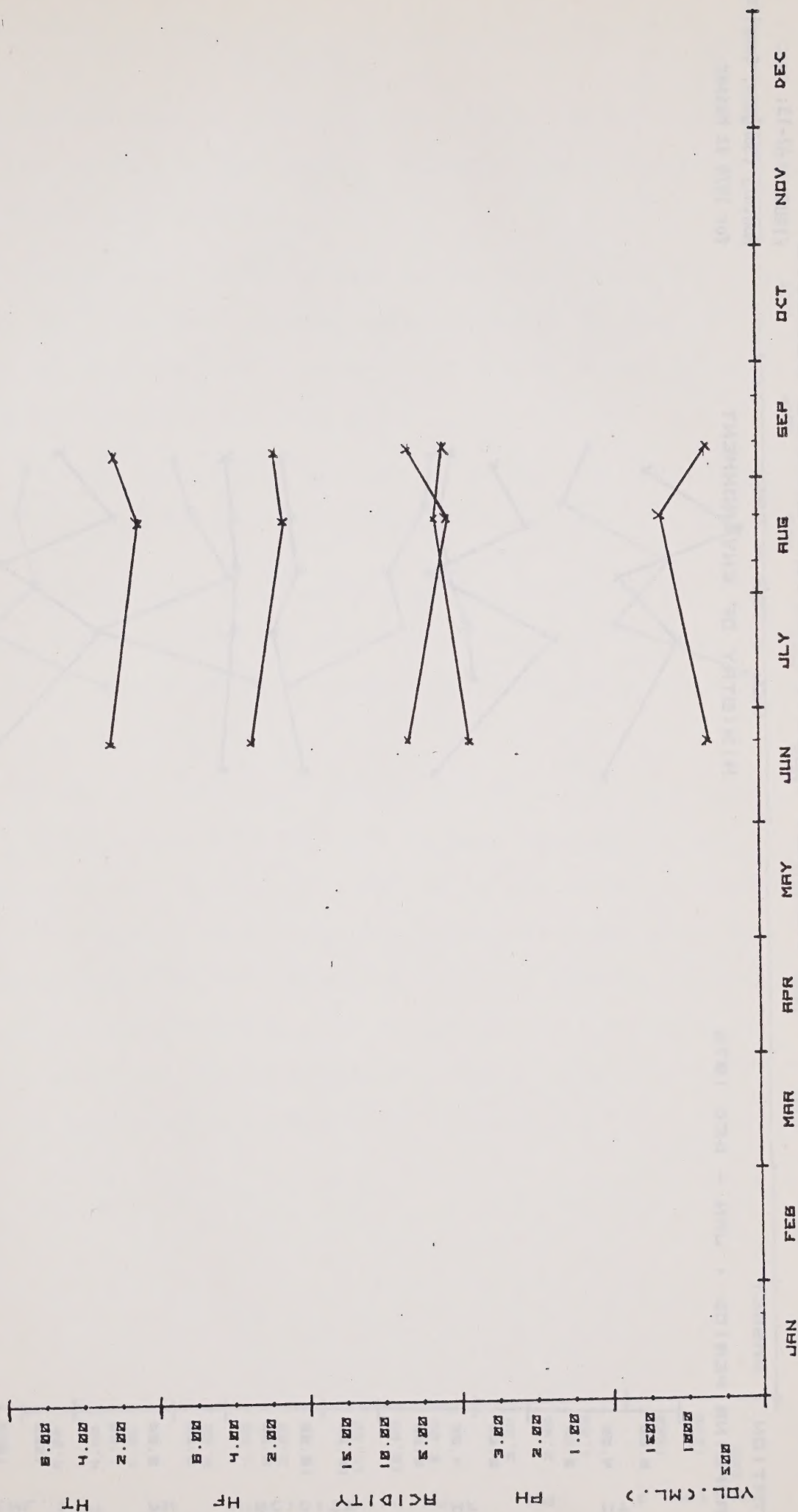
FIGURE A2-12:

Monthly (Sangamo) Sampling Results
for 1978 at Ramsey

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : RAMSEY
SAMPLING PERIOD : JAN - DEC 1978

DEPOSITION (MG/M2)



MONTHLY PRECIPITATION SAMPLE RESULTS

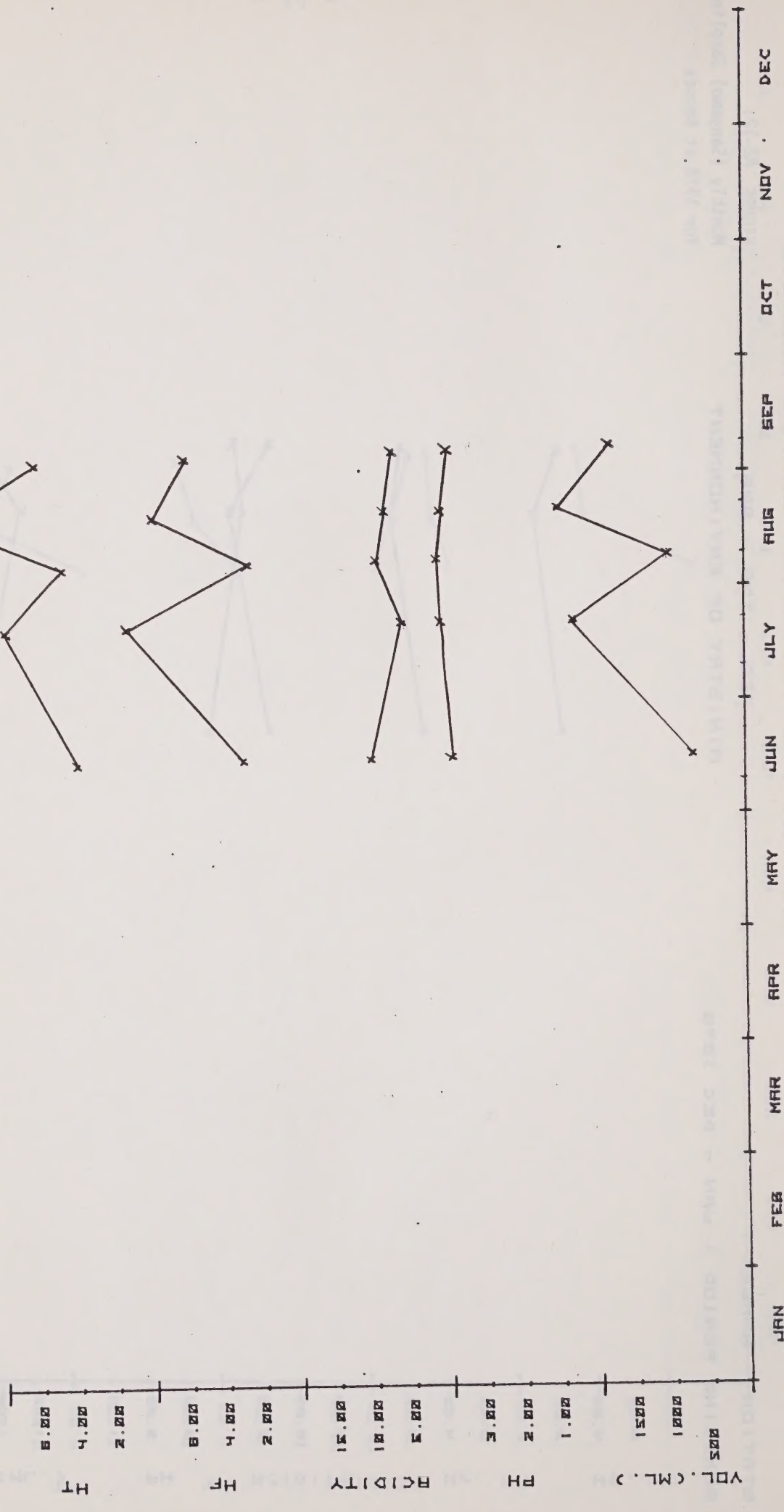
FIGURE A2-13:

Monthly (Sangamo) Sampling Results
for 1978 at Massey

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION: MASSEY

SAMPLING PERIOD: JAN - DEC 1978



MONTHLY PRECIPITATION SAMPLE RESULTS

FIGURE A2-14:

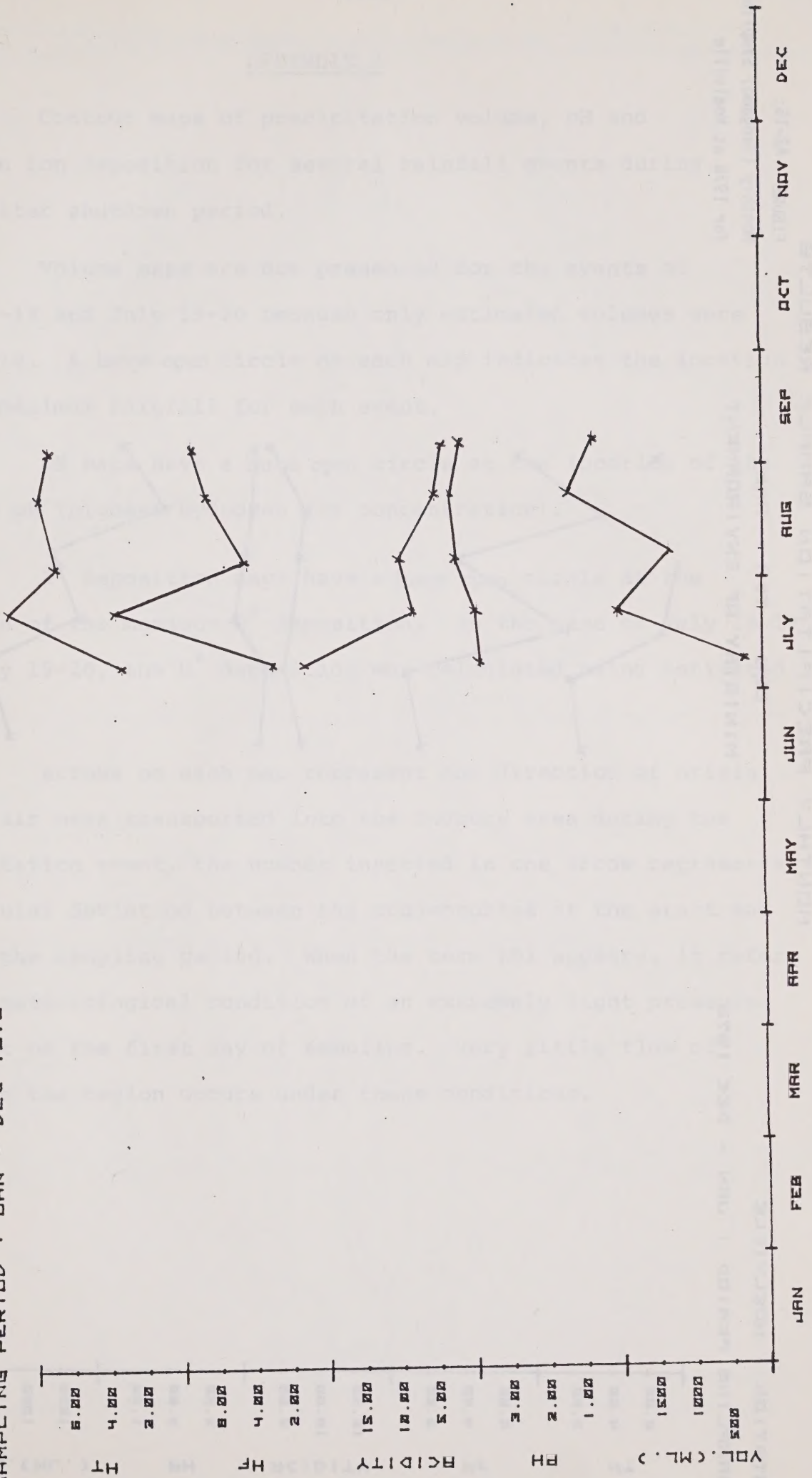
Monthly (Sangamo) Sampling Results
for 1978 at River Valley

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : RIVER VALLEY

SAMPLING PERIOD : JAN - DEC 1978

DEPOSITION (MG/M2)



MONTHLY PRECIPITATION SAMPLE RESULTS

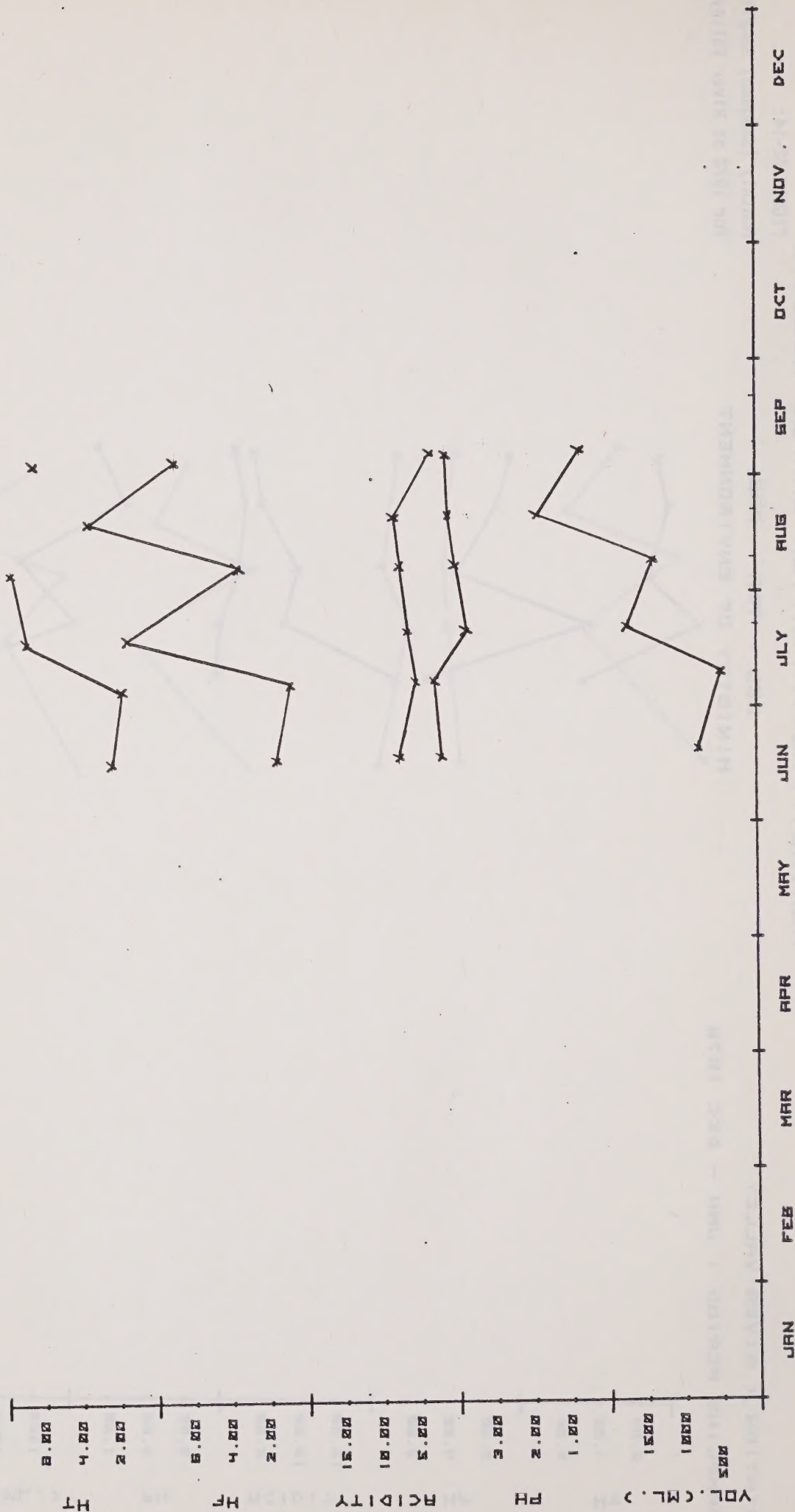
FIGURE A2-15:

Monthly (Sangamo) Sampling Results
for 1978 at Noelville

SES - TDA - ARB
MINISTRY OF ENVIRONMENT

STATION : NOELVILLE
SAMPLING PERIOD : JAN - DEC 1978

DEPOSITION (MG/M2)



APPENDIX 3

Contour maps of precipitation volume, pH and hydrogen ion deposition for several rainfall events during the smelter shutdown period.

Volume maps are not presented for the events of July 18-19 and July 19-20 because only estimated volumes were available. A large open circle on each map indicates the location of the maximum rainfall for each event.

pH maps have a large open circle at the location of the minimum pH (highest hydrogen ion concentration).

H^+ deposition maps have a large open circle at the location of the maximum H^+ deposition. In the case of July 18-19 and July 19-20, the H^+ deposition was calculated using estimated volumes.

Arrows on each map represent the direction of origin of the air mass transported into the Sudbury area during the precipitation event, the number inserted in one arrow represents the angular deviation between the trajectories at the start and end of the sampling period. When the term LGL appears, it refers to the meteorological condition of an extremely light pressure gradient on the first day of sampling. Very little flow of air into the region occurs under these conditions.

result

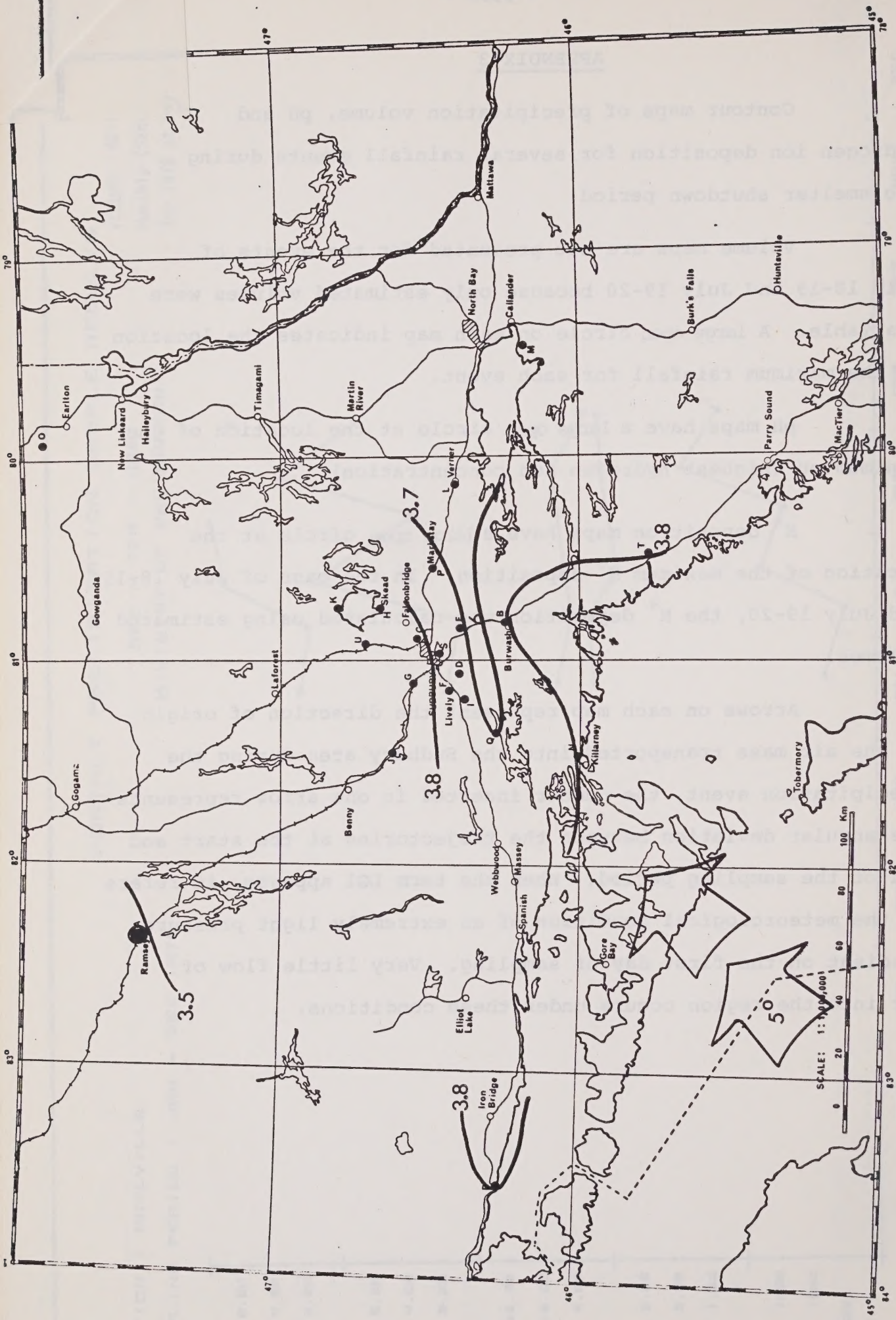


FIGURE A3-1A : Contours of Precipitation pH - July 18-19, 1978

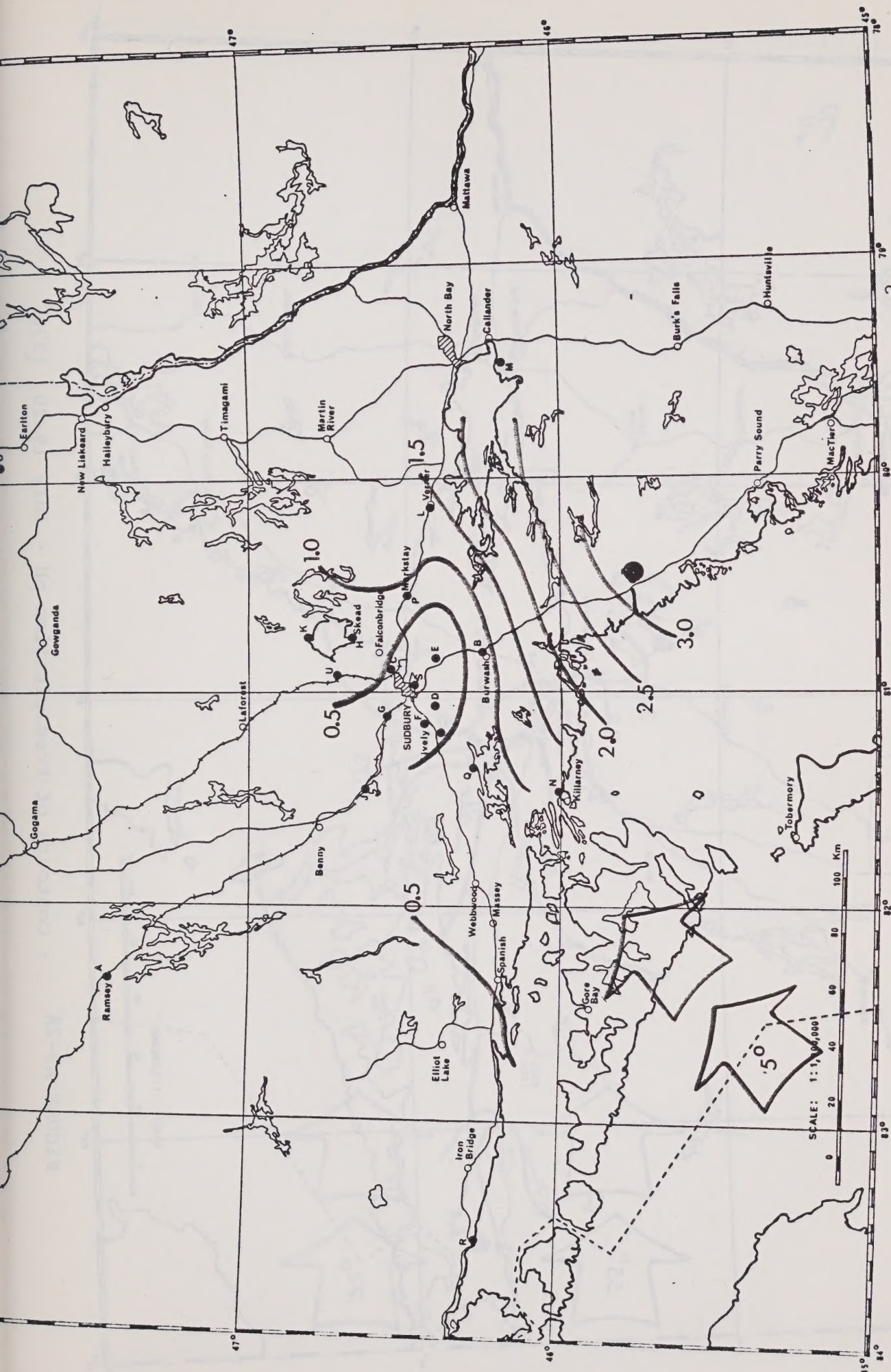


FIGURE A3-1B : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- July 18-19, 1978

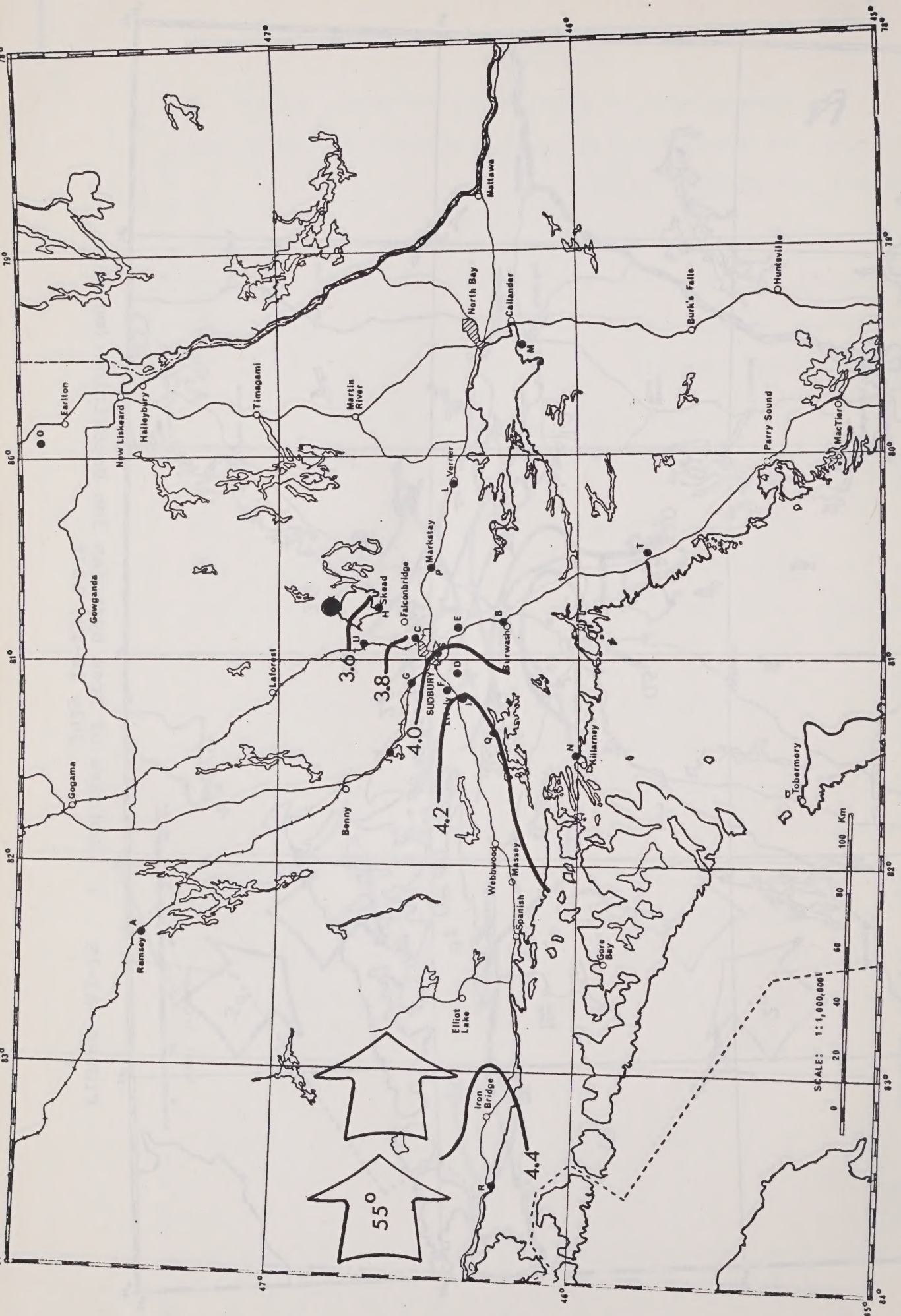


FIGURE A3-2A : Contours of Precipitation pH - July 19-20, 1978

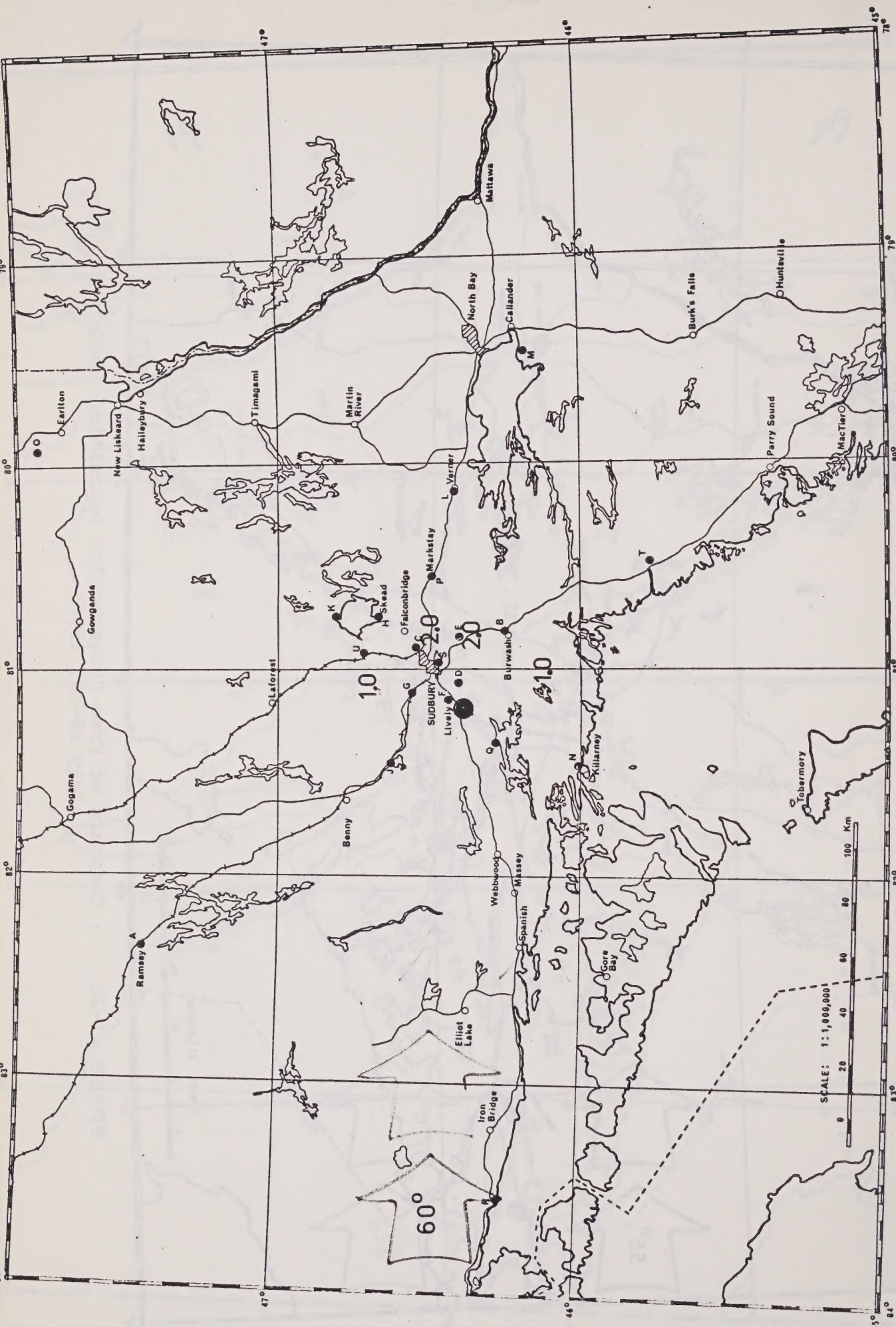


FIGURE A3-3A : Contours of Collected Precipitation Volume(1)
- July 22-23, 1978

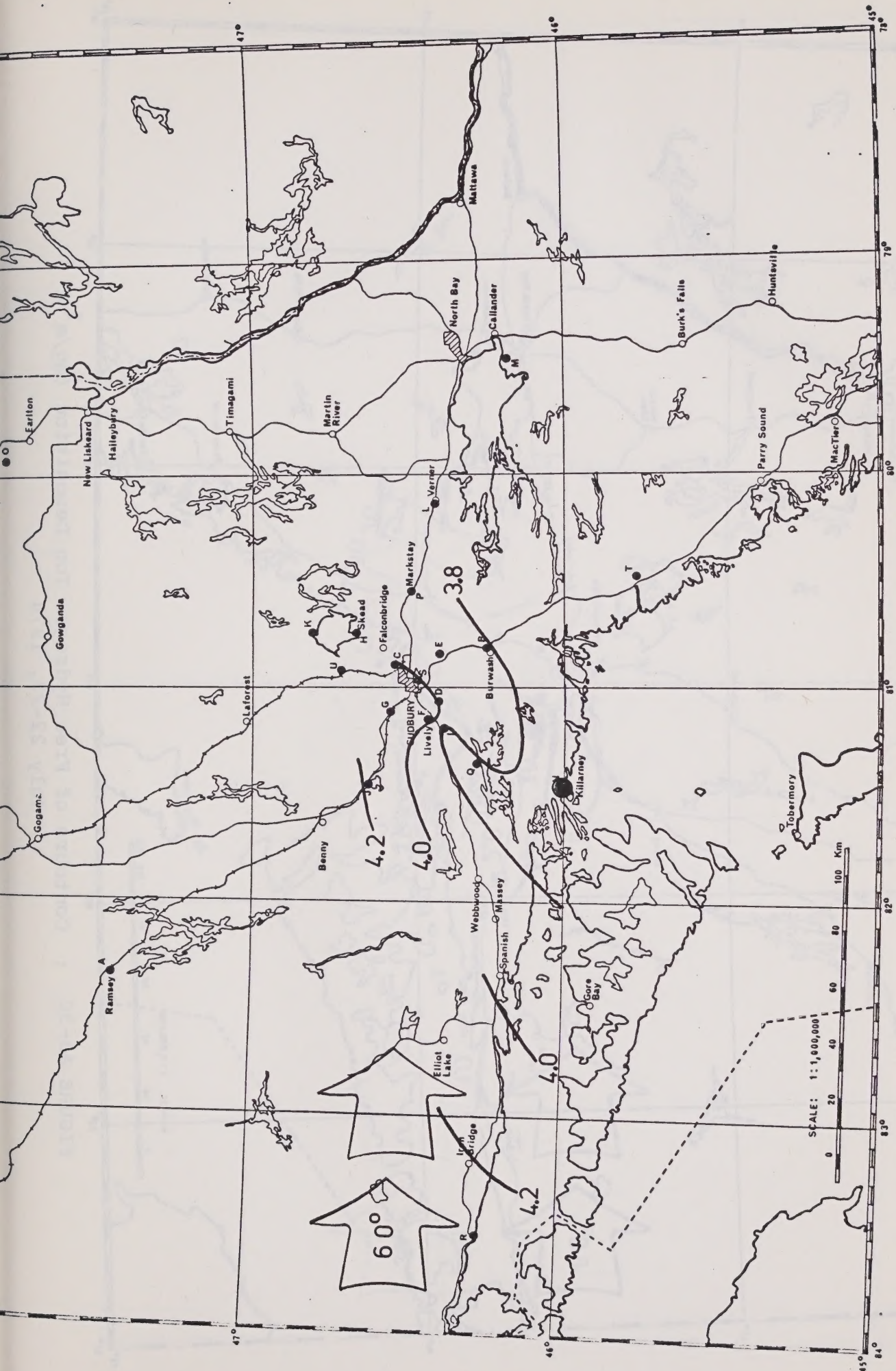


FIGURE A3-3B : Contours of Precipitation pH - July 22-23, 1978

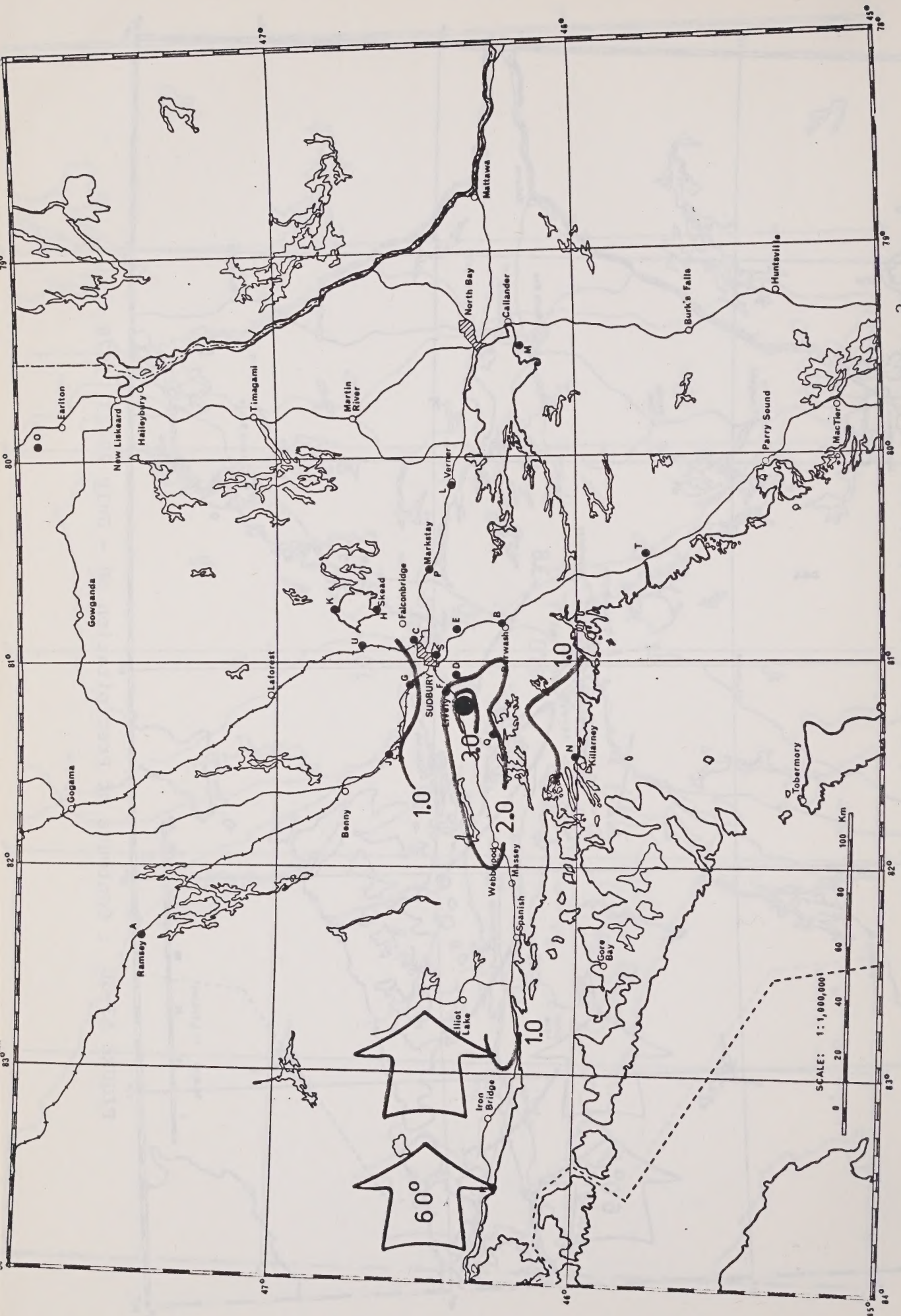


FIGURE A3-3C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- July 22-23, 1978

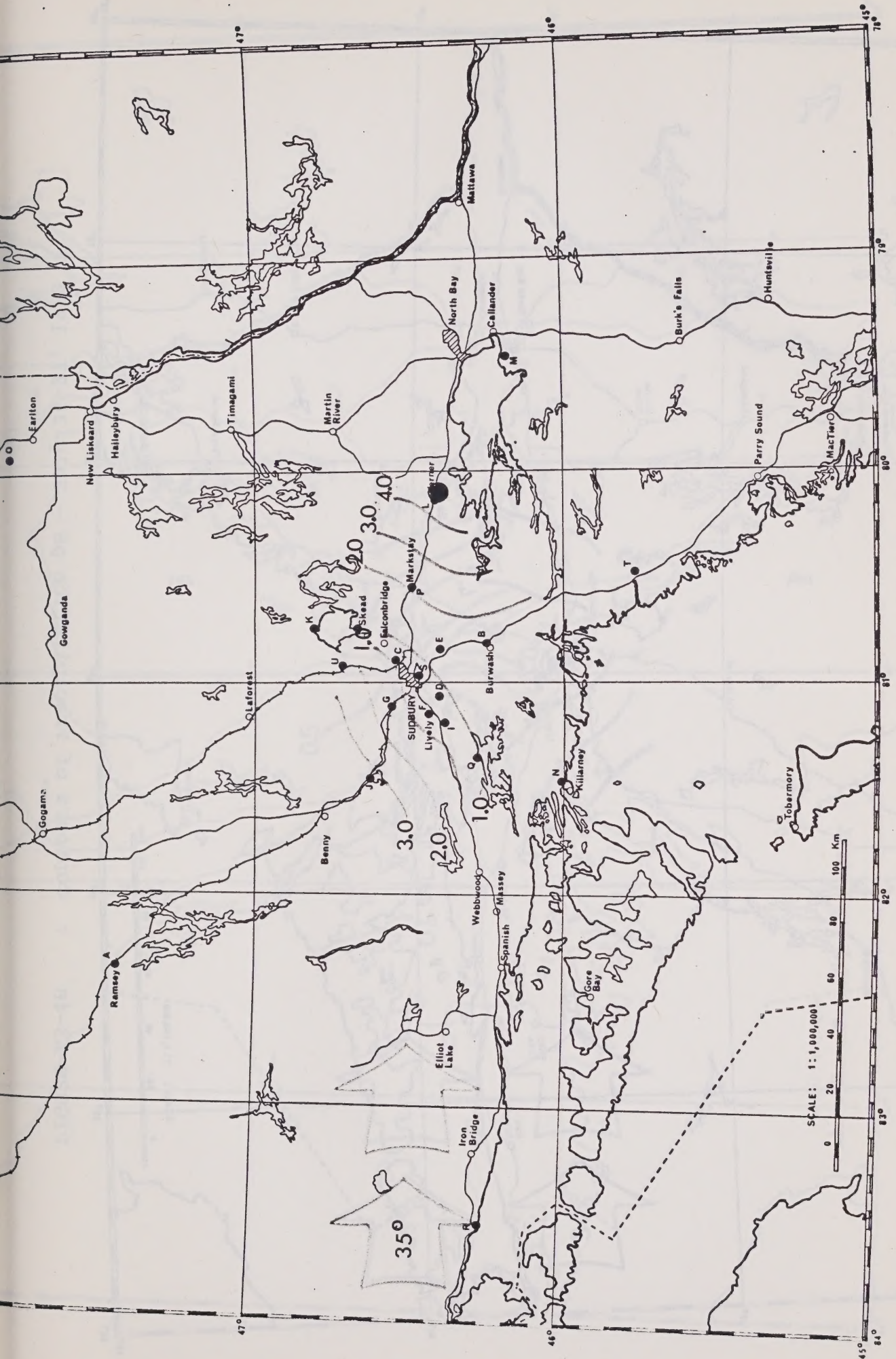


FIGURE A3-4A : Contours of Collected Precipitation Volume (1)
- July 26-27, 1978

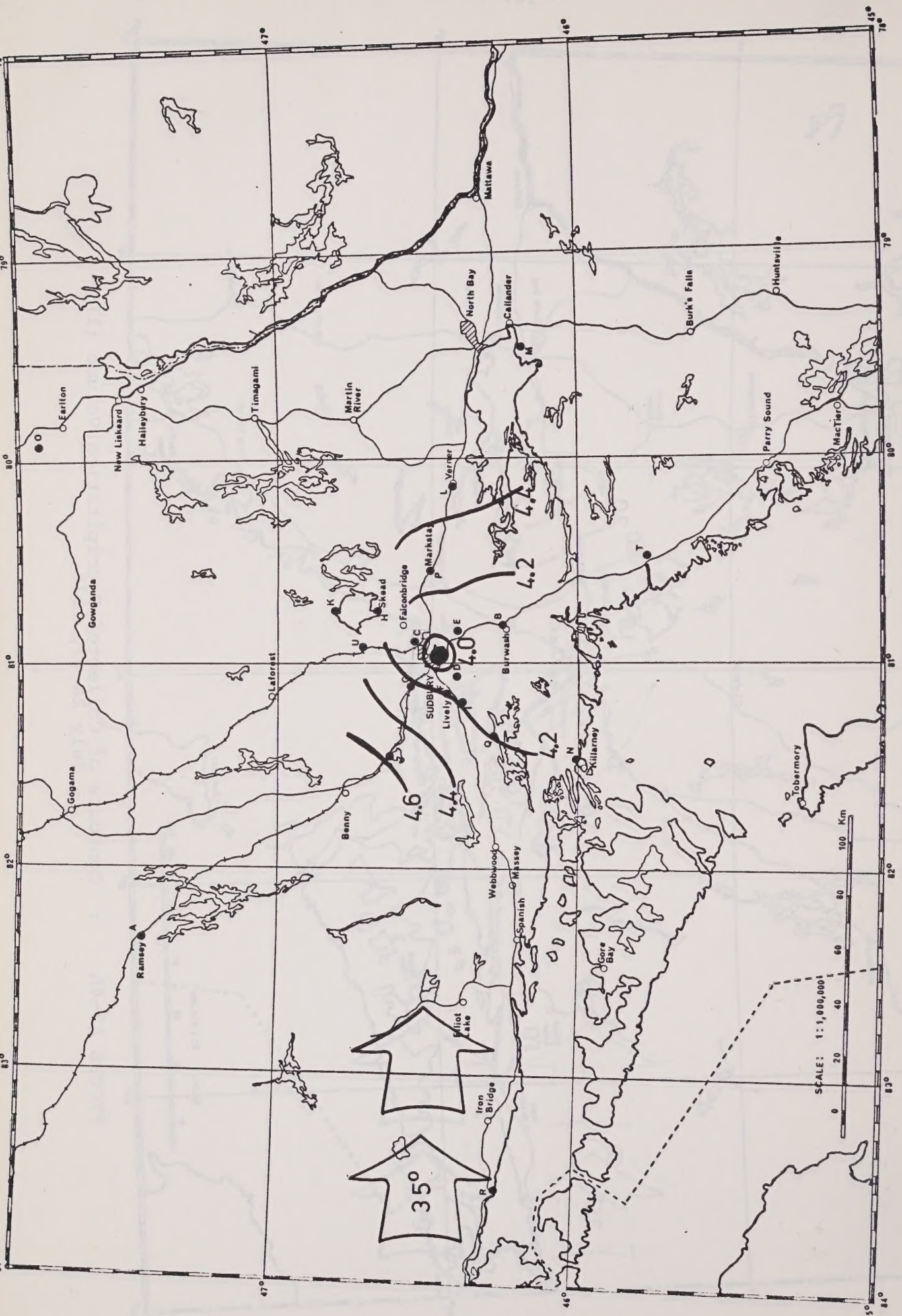


FIGURE A3-4B : Contours of Precipitation pH - July 26-27, 1978

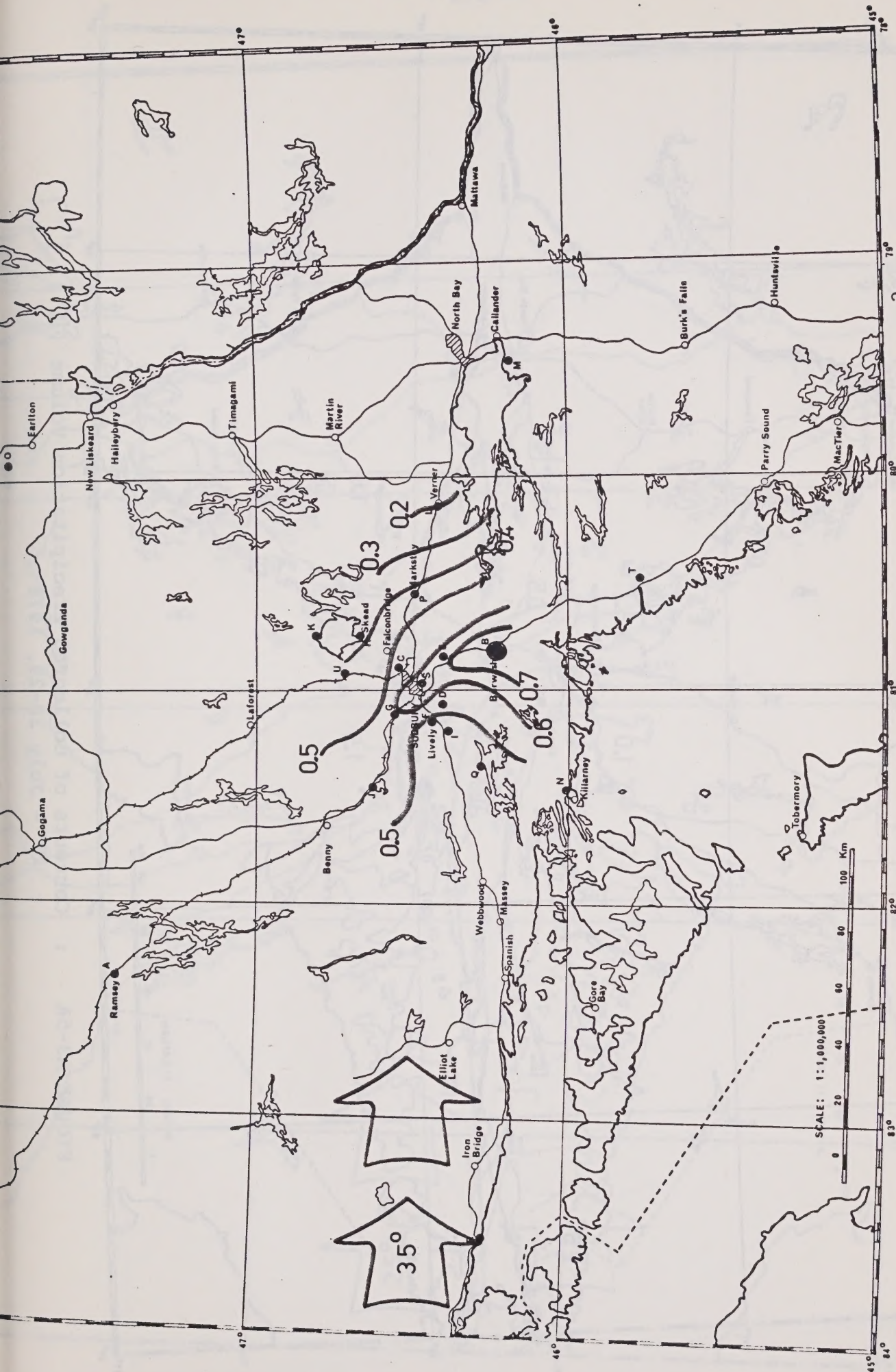


FIGURE A3-4C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- July 26-27, 1978

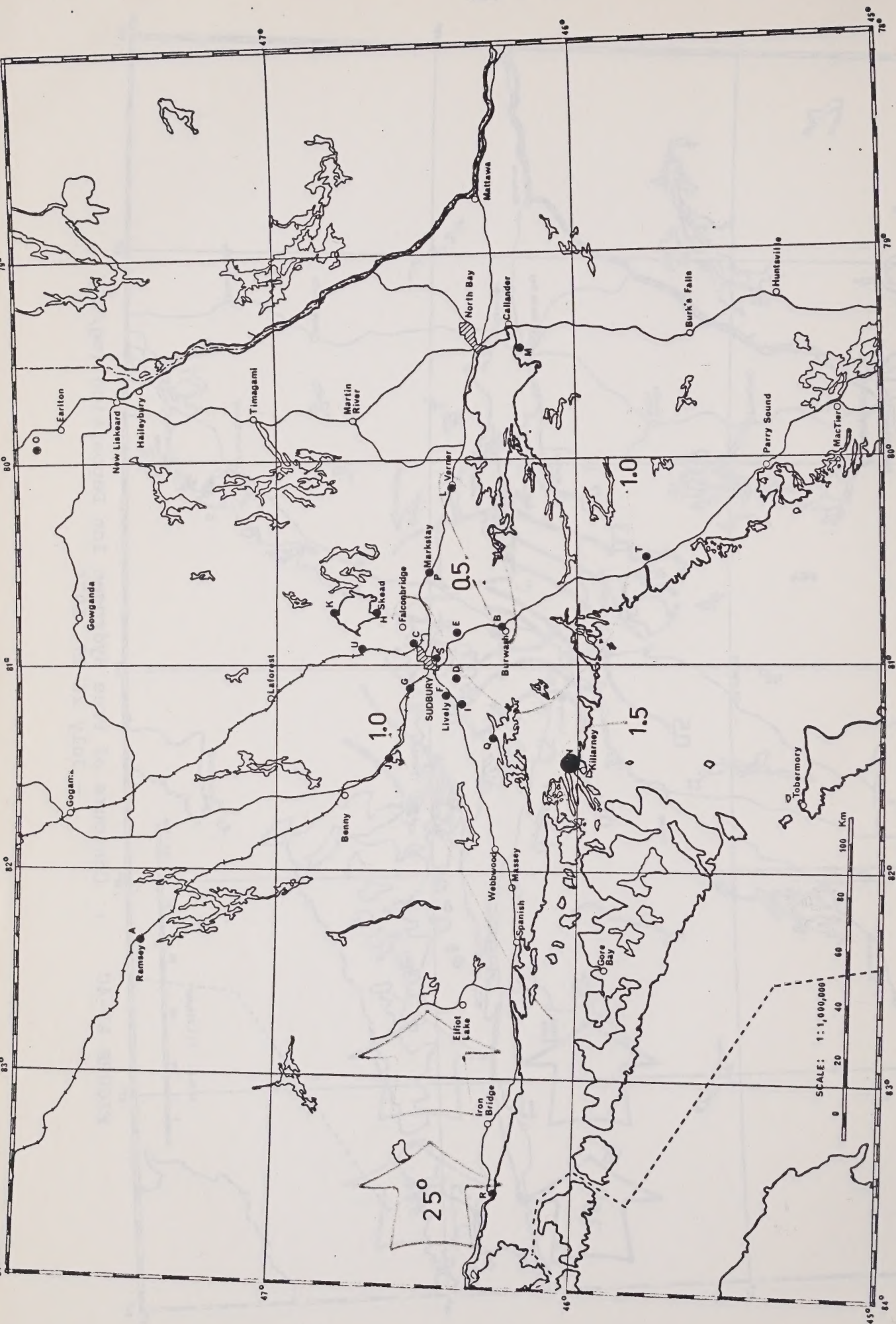


FIGURE A3-5A : Contours of Collected Precipitation Volume (1)

- July 28-29, 1978

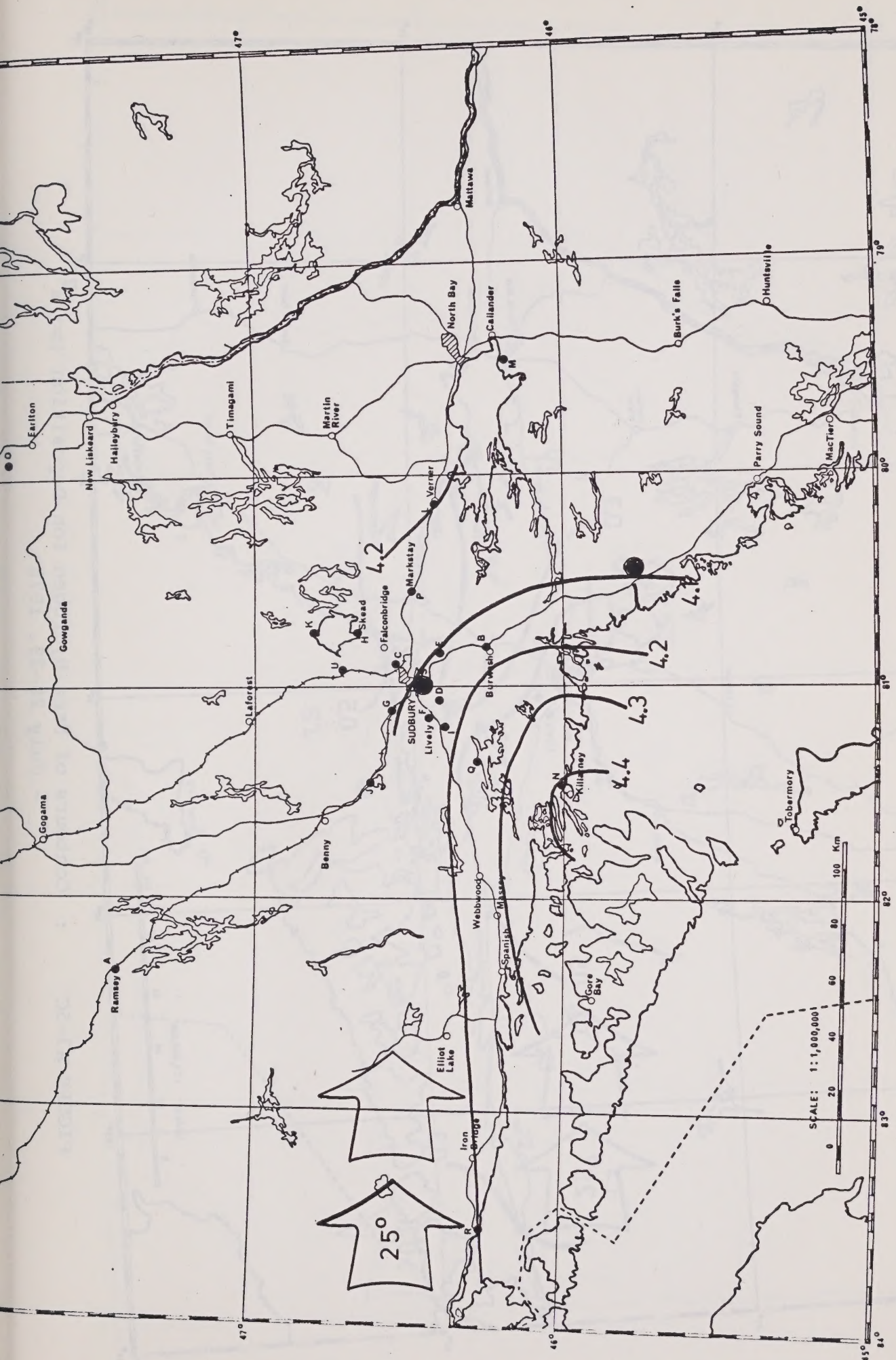


FIGURE A3-5B : Contours of Precipitation pH - July 28-29, 1978

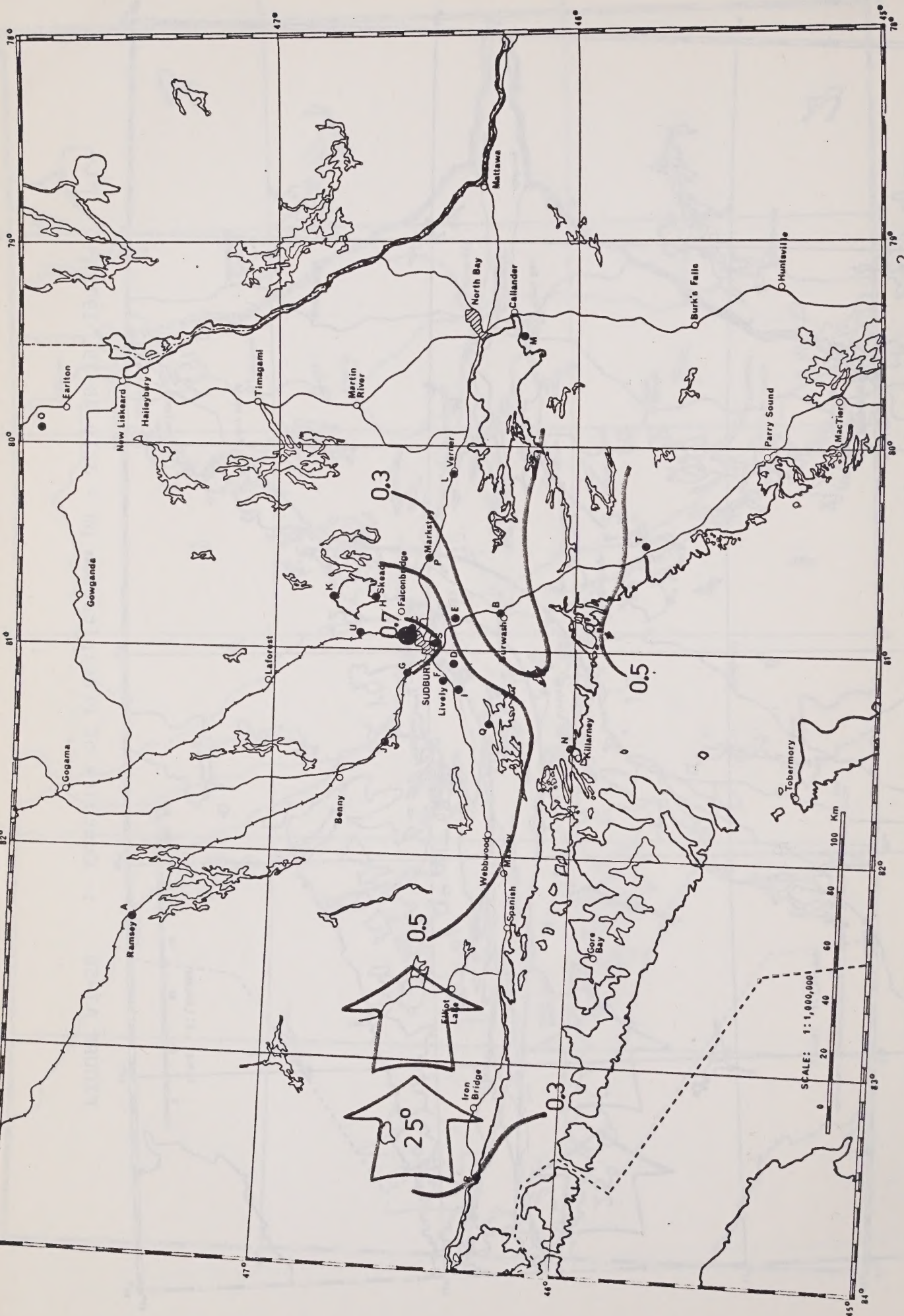


FIGURE A3-5C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- July 28-29, 1978

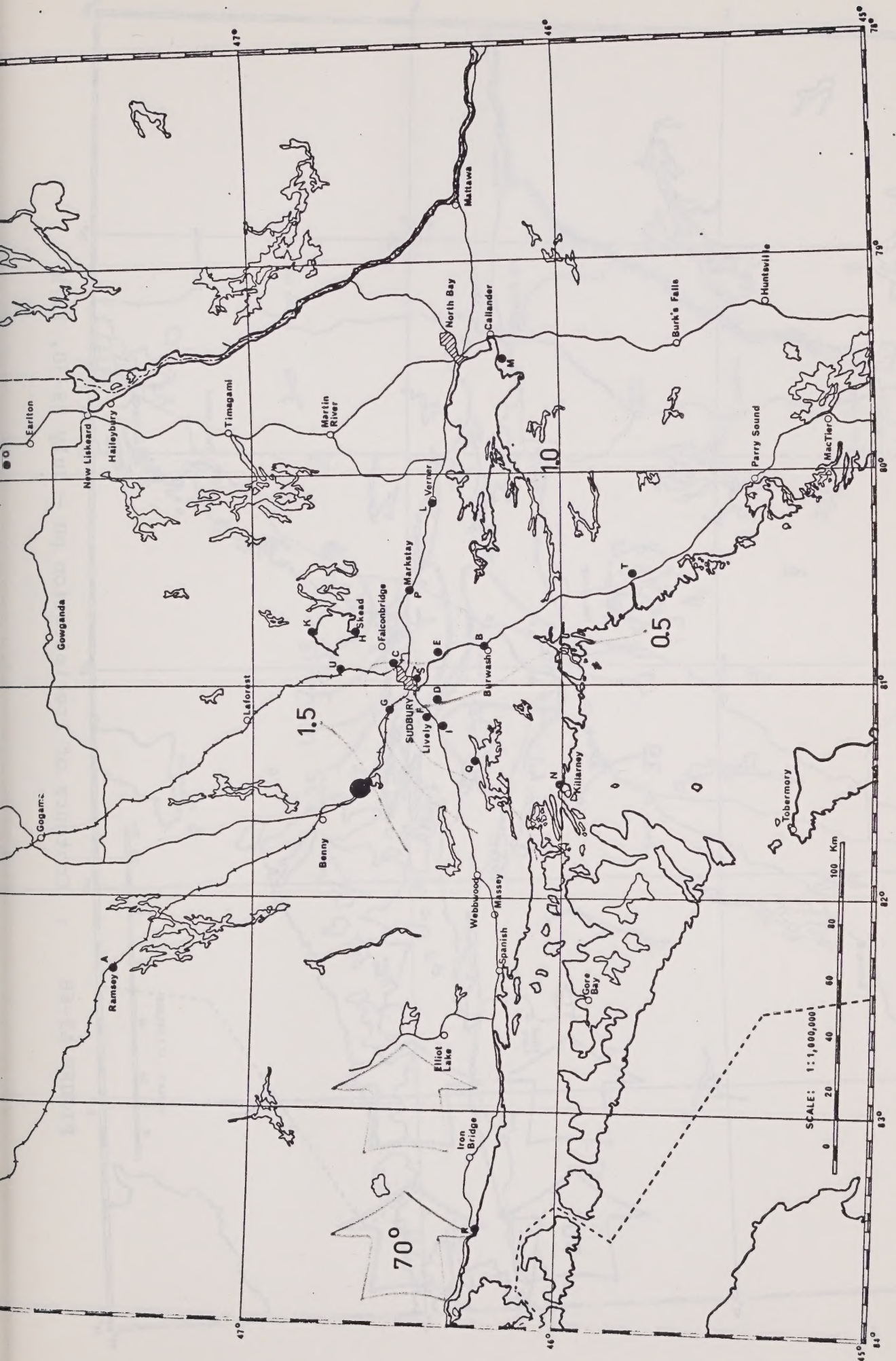


FIGURE A3-6A : Contours of Collected Precipitation Volume (1)

- July 29-30, 1978

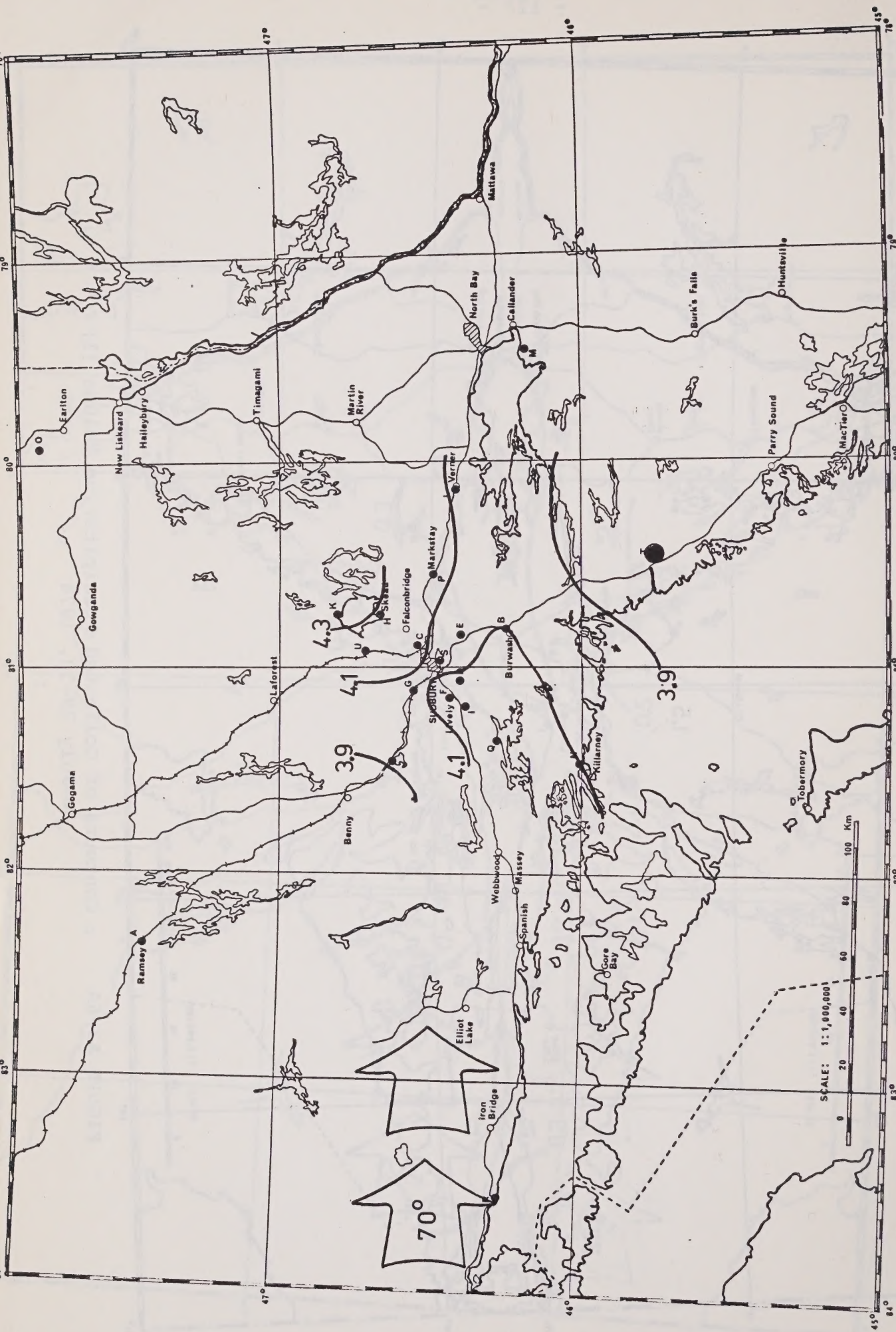


FIGURE A3-6B : Contours of Precipitation pH - July 29-30, 1978

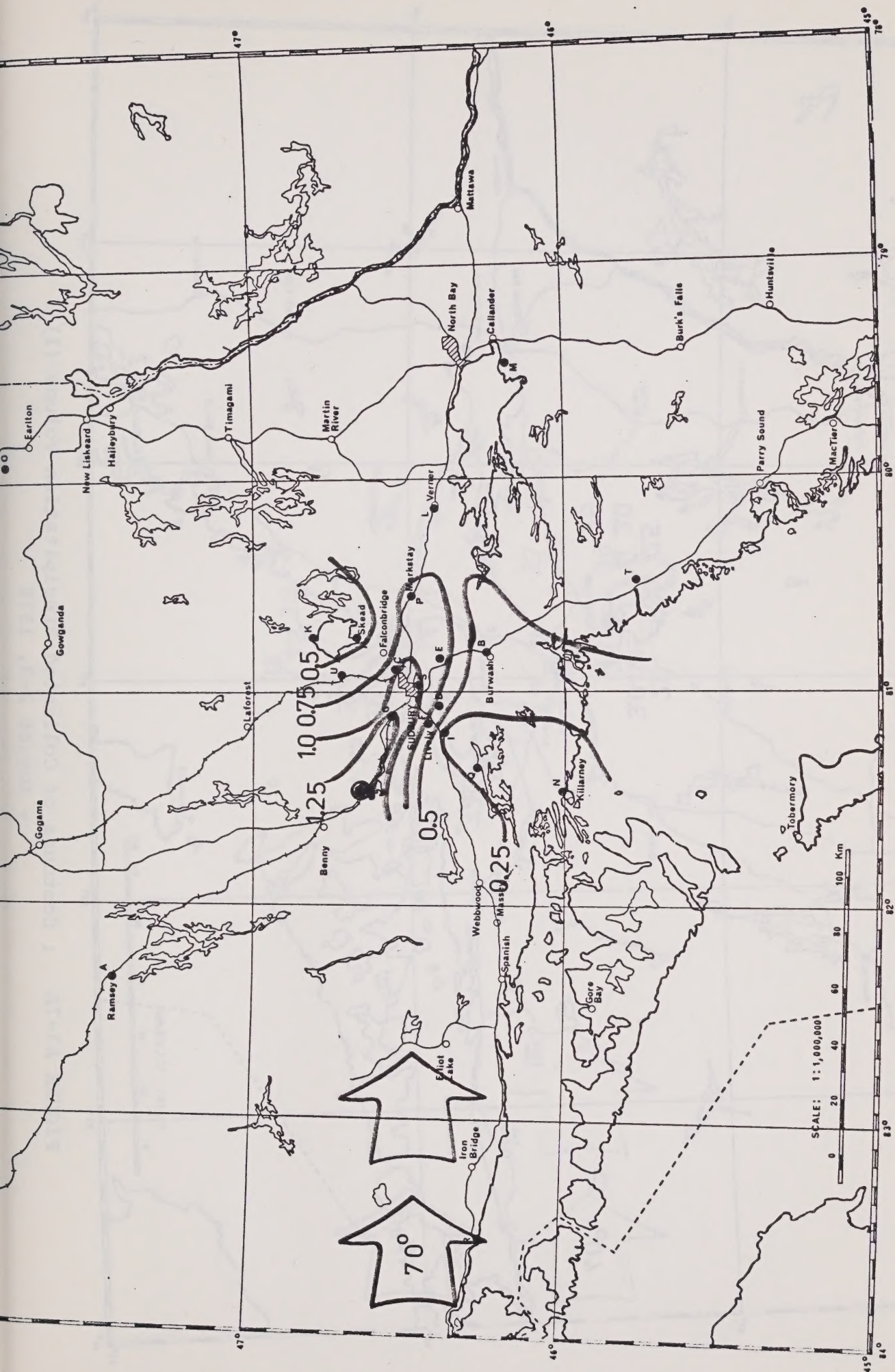


FIGURE A3-6C : Contours of Free Hydrogen Ion Deposition (mg/m^2)

- July 29-30, 1978

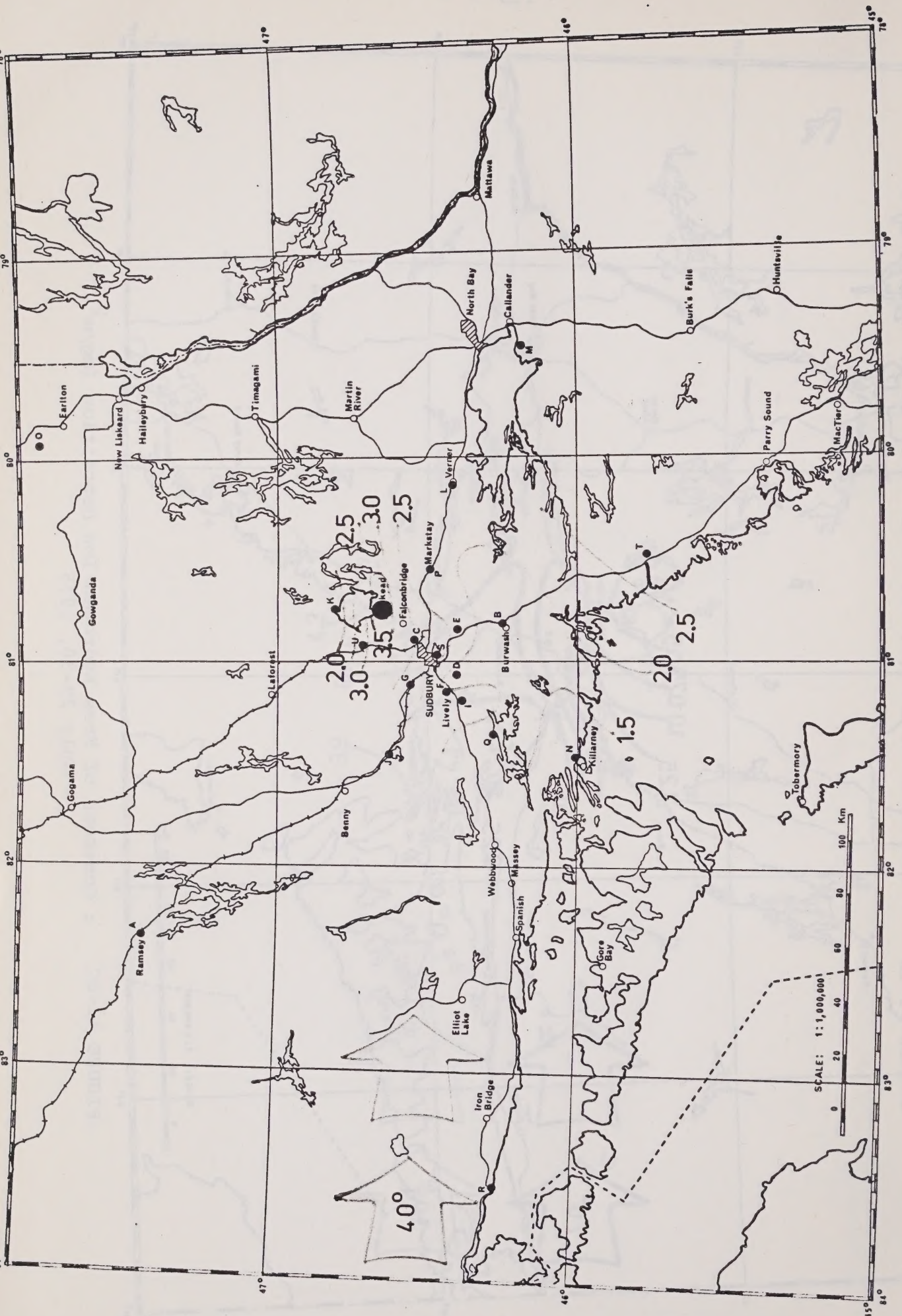


FIGURE A3-7A : Contours of Collected Precipitation Volume (1).
- August 2-3, 1978

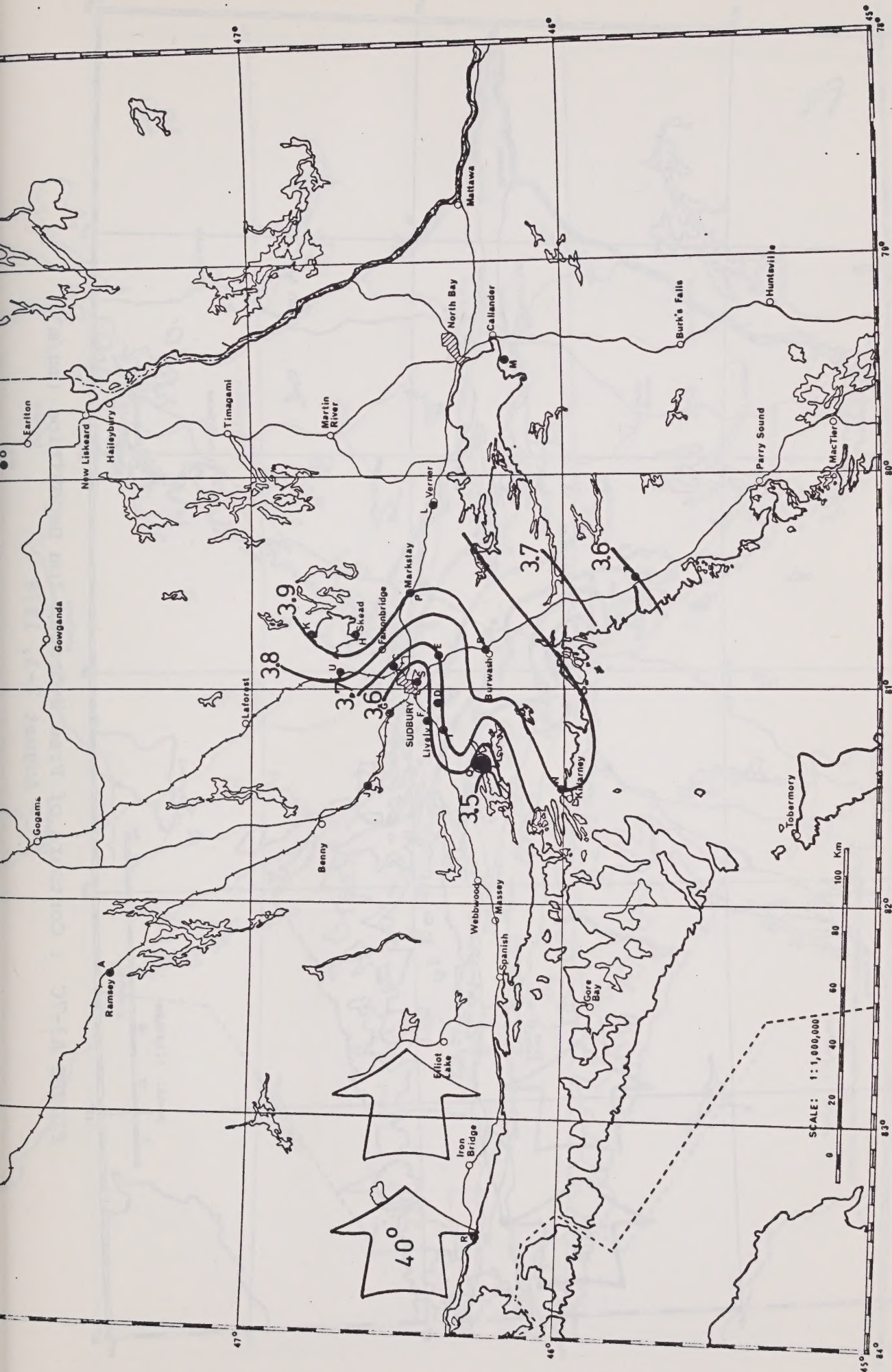


FIGURE A3-7B : Contours of Precipitation pH - August 2-3, 1978

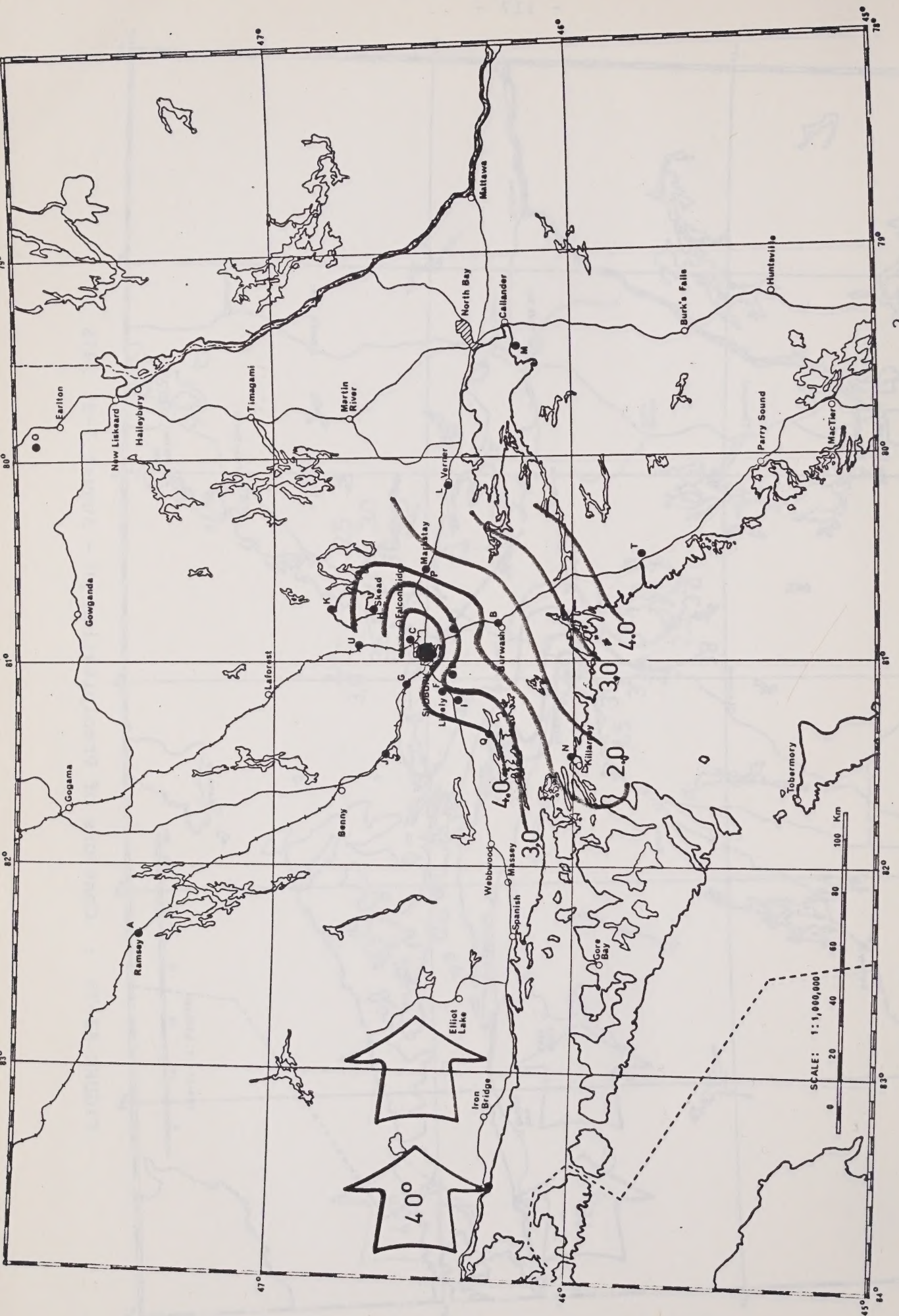


FIGURE A3-7C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- August 2-3, 1978

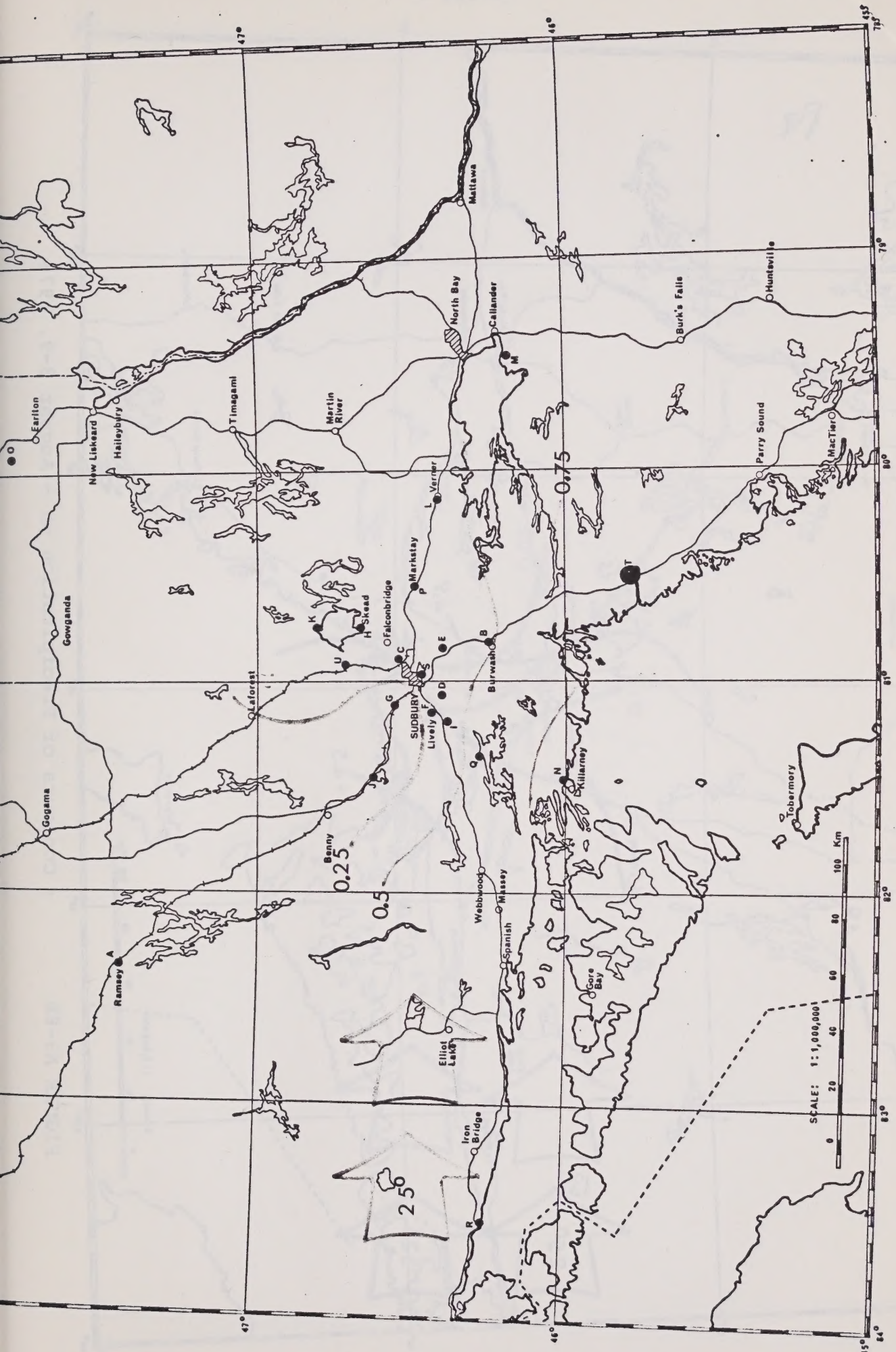


FIGURE A3-8A : Contours of Collected Precipitation Volume (1)
- August 8-9, 1978

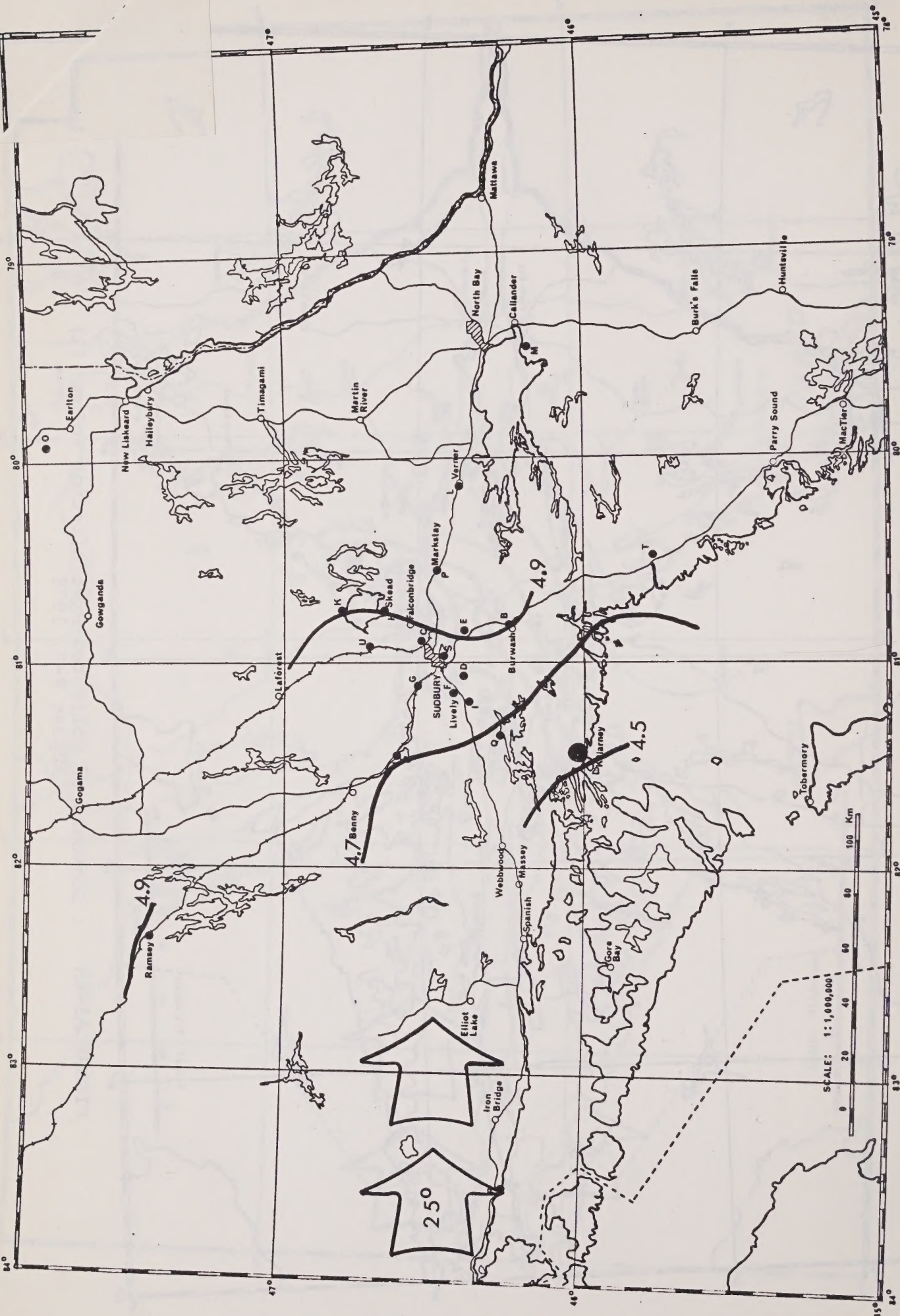


FIGURE A3-8B : Contours of Precipitation pH - August 8-9, 1978

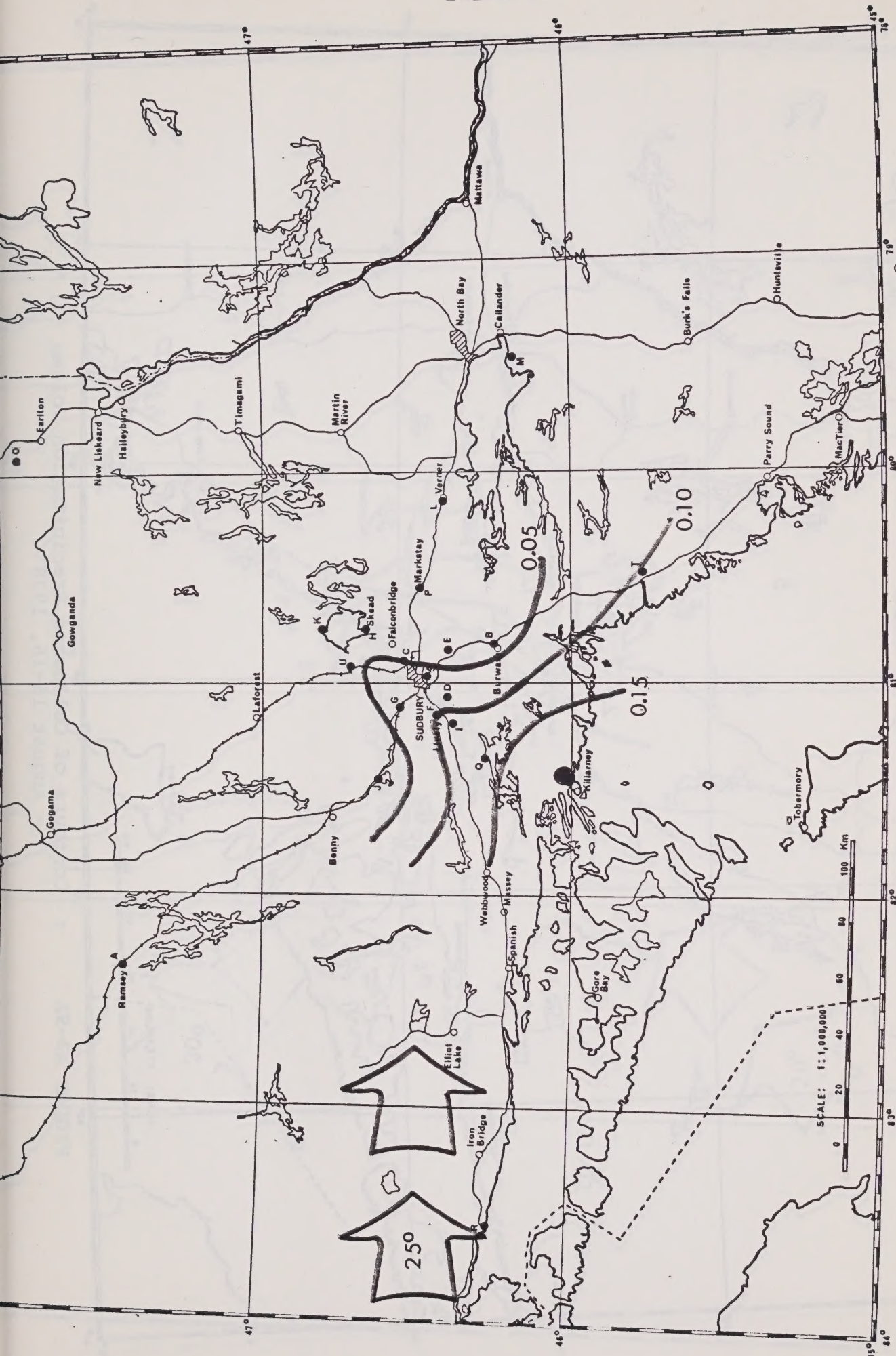


FIGURE A3-8C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- August 8-9, 1978

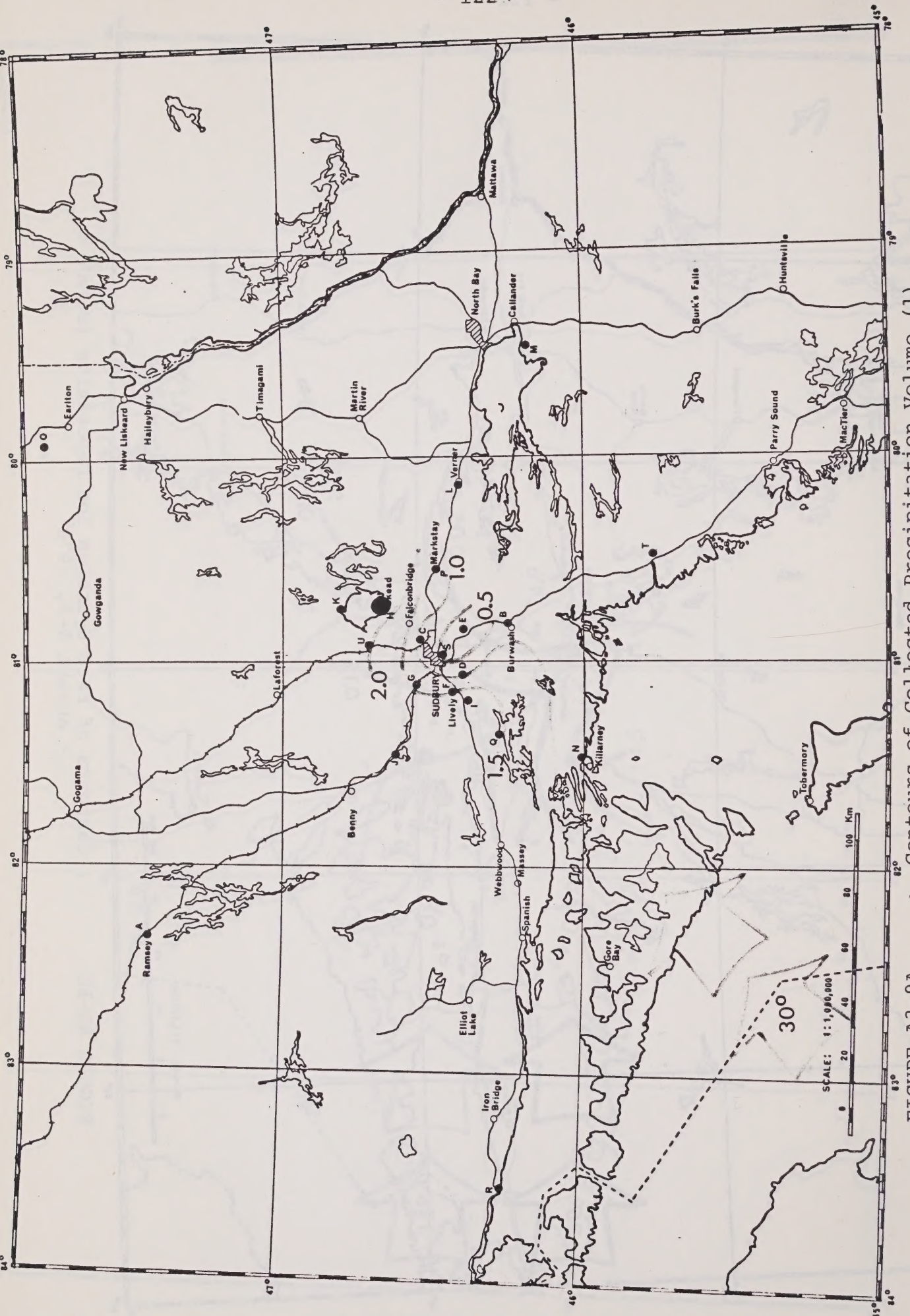


FIGURE A3-9A : Contours of Collected Precipitation Volume (1)
- August 15-16, 1978

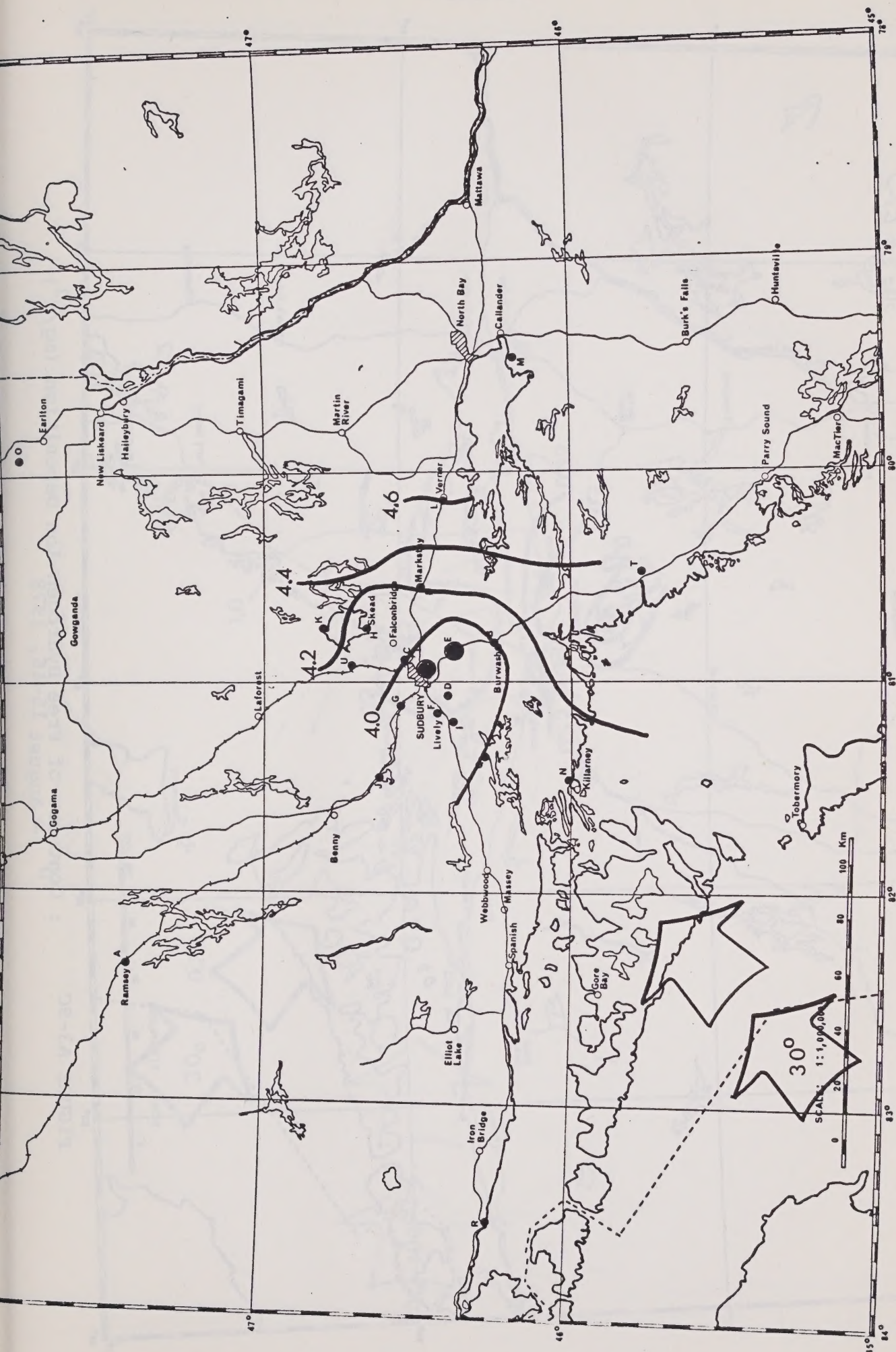


FIGURE A3-9B : Contours of Precipitation pH - August 15-16, 1978

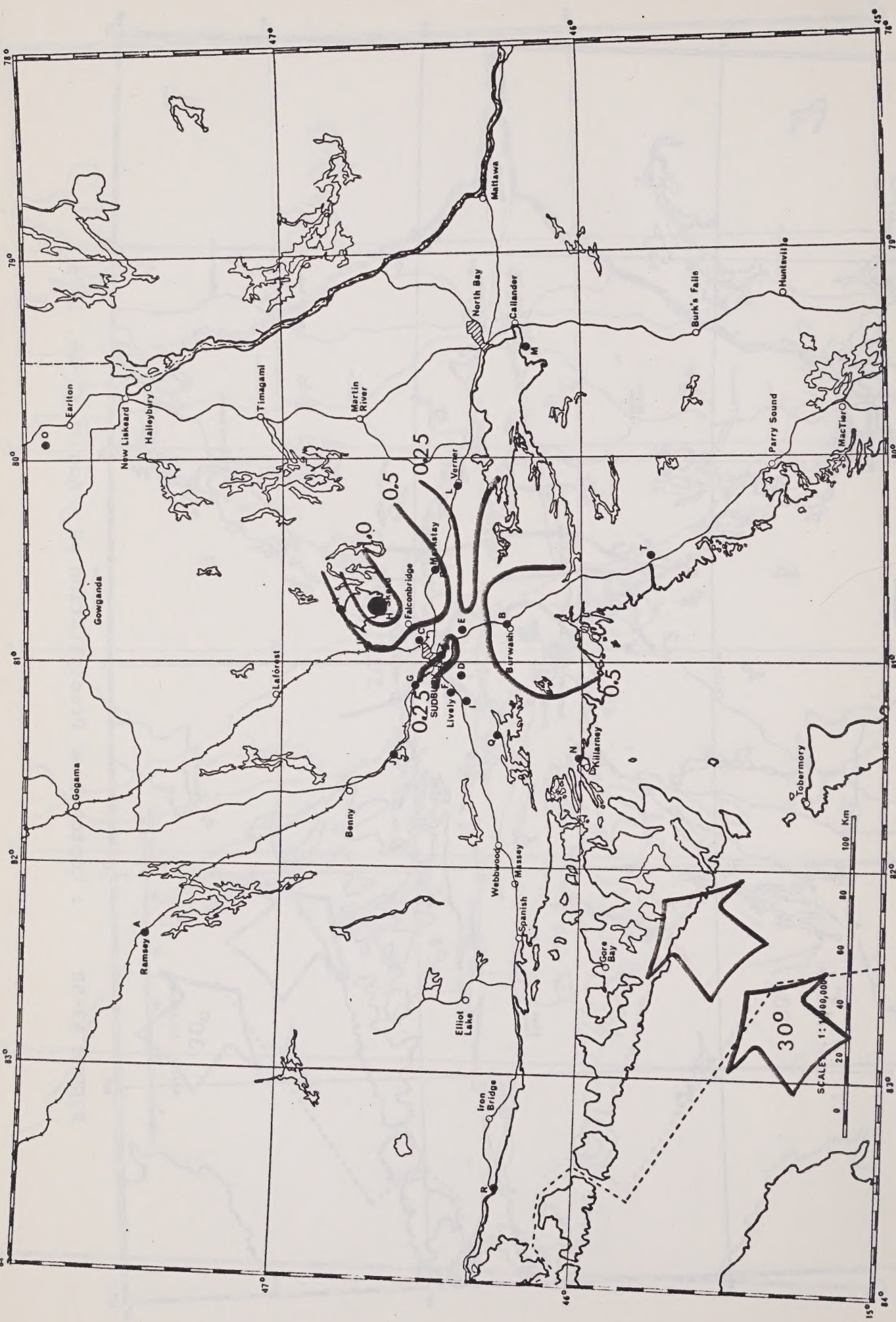


FIGURE A3-9C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- August 15-16, 1978

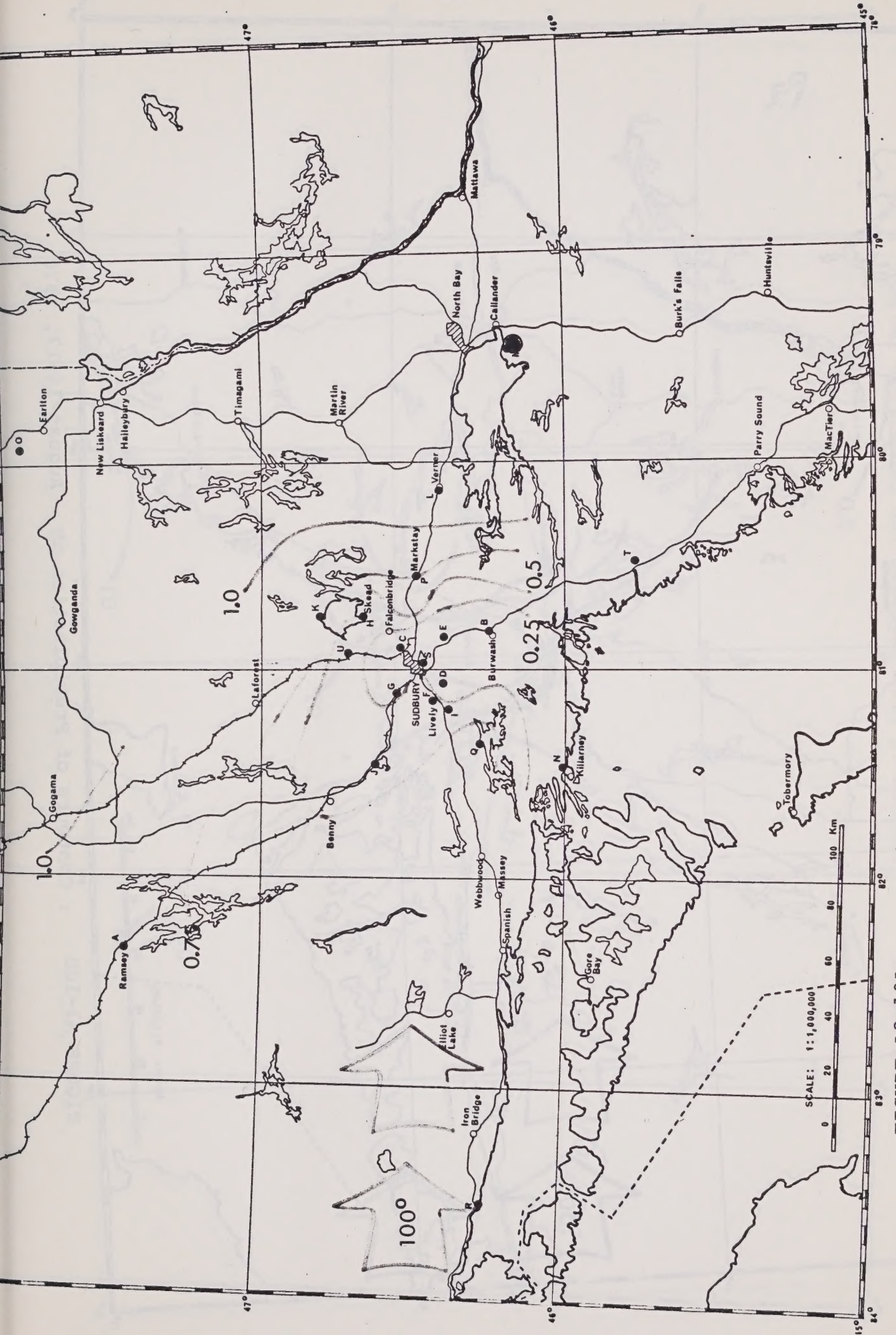


FIGURE A3-10A : Contour of Collected Precipitation Volume (1)
- August 16-17, 1978

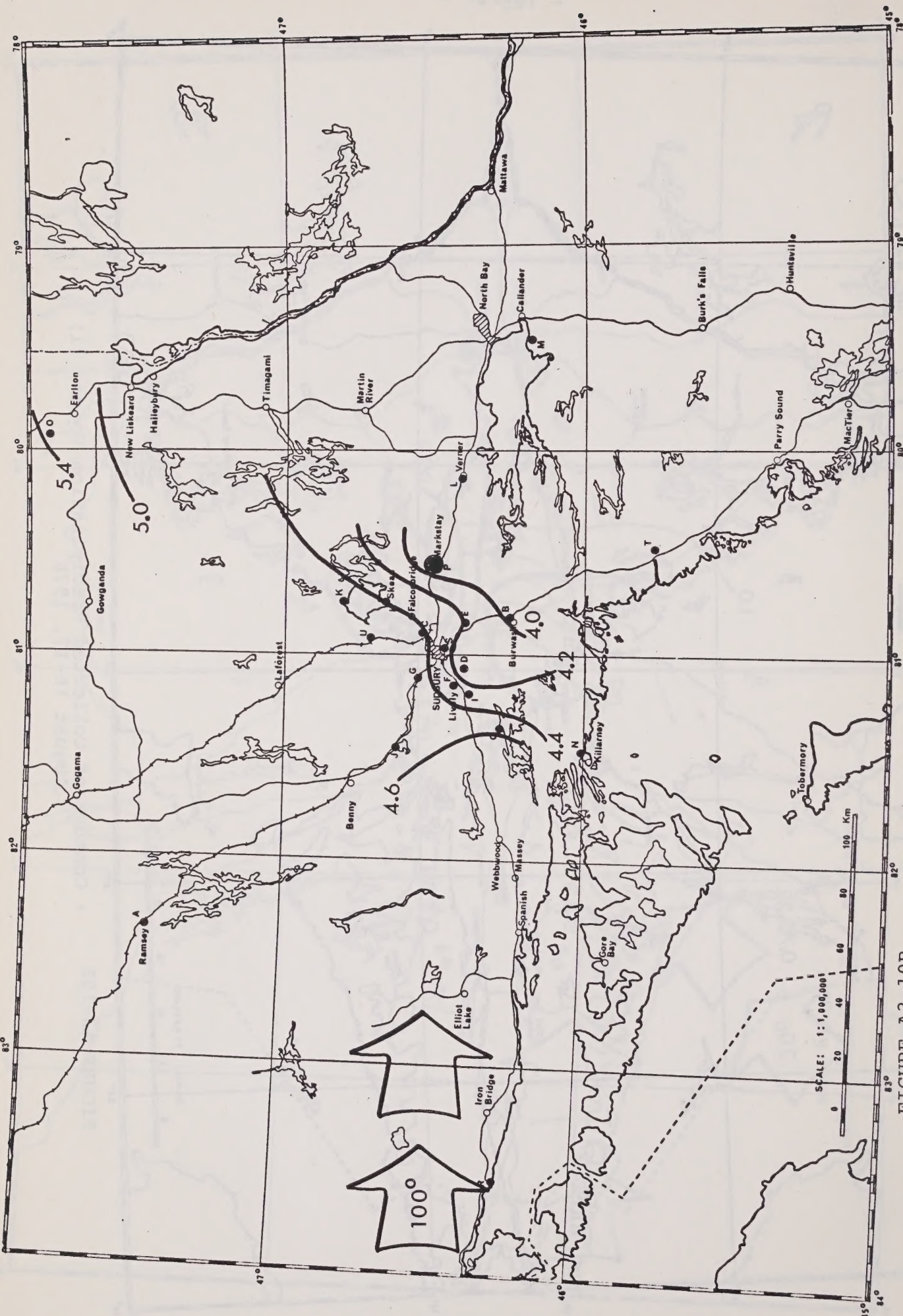


FIGURE A3-10B : Contours of Precipitation pH - August 16-17, 1978

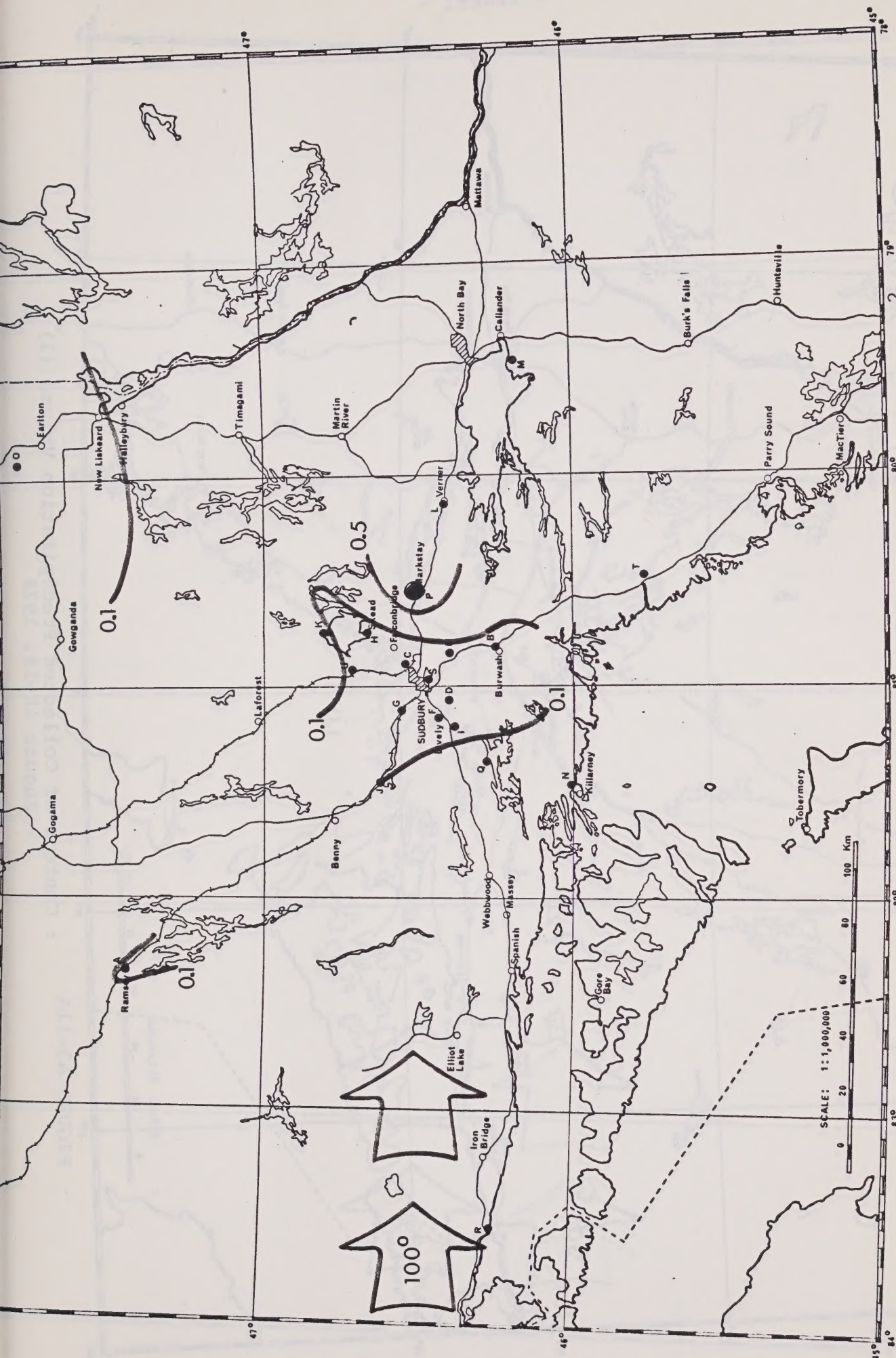


FIGURE A3-10C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- August 16-17, 1978

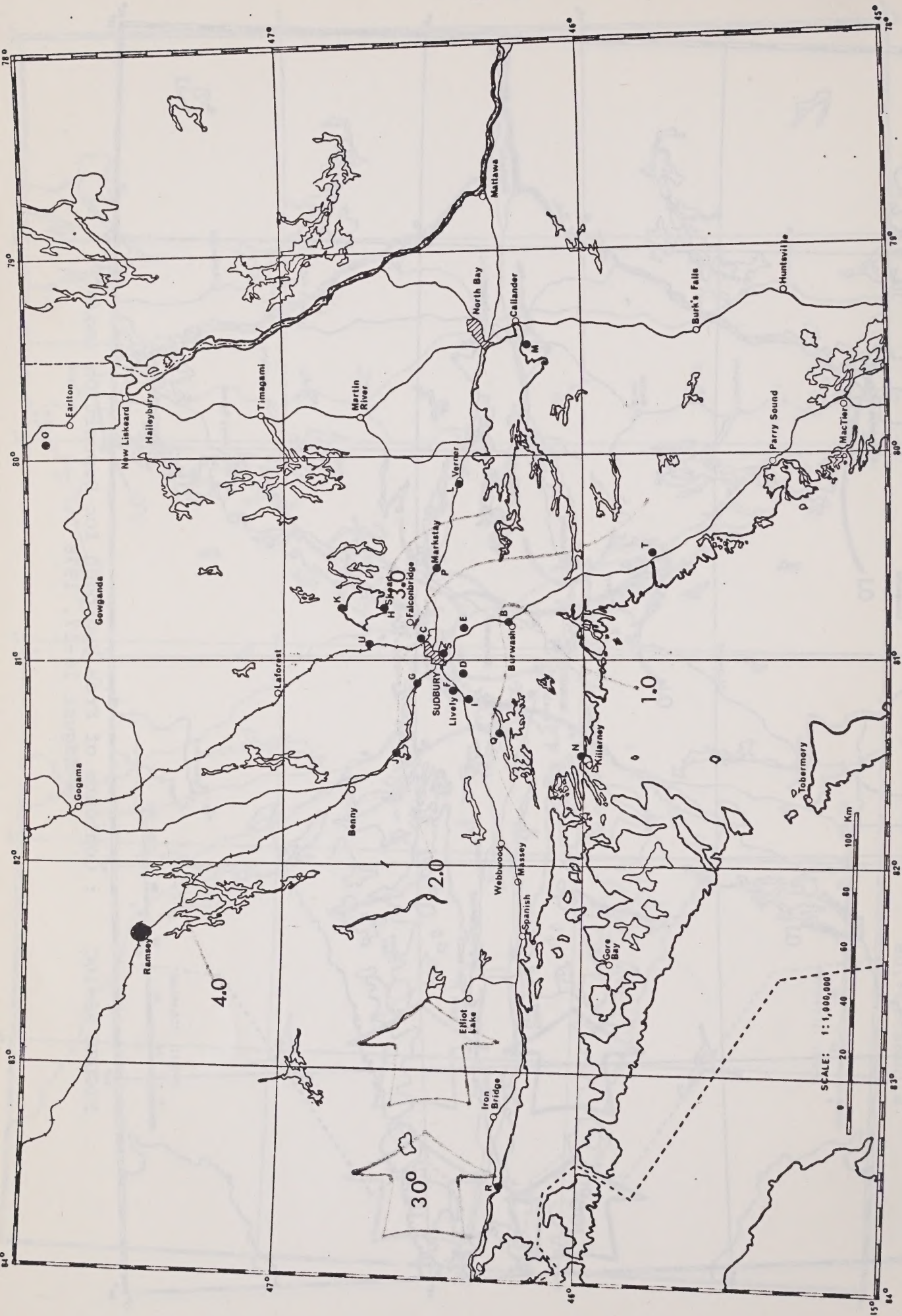


FIGURE A3-11A : Contour of Collected Precipitation Volume (1)
- August 18-19, 1978

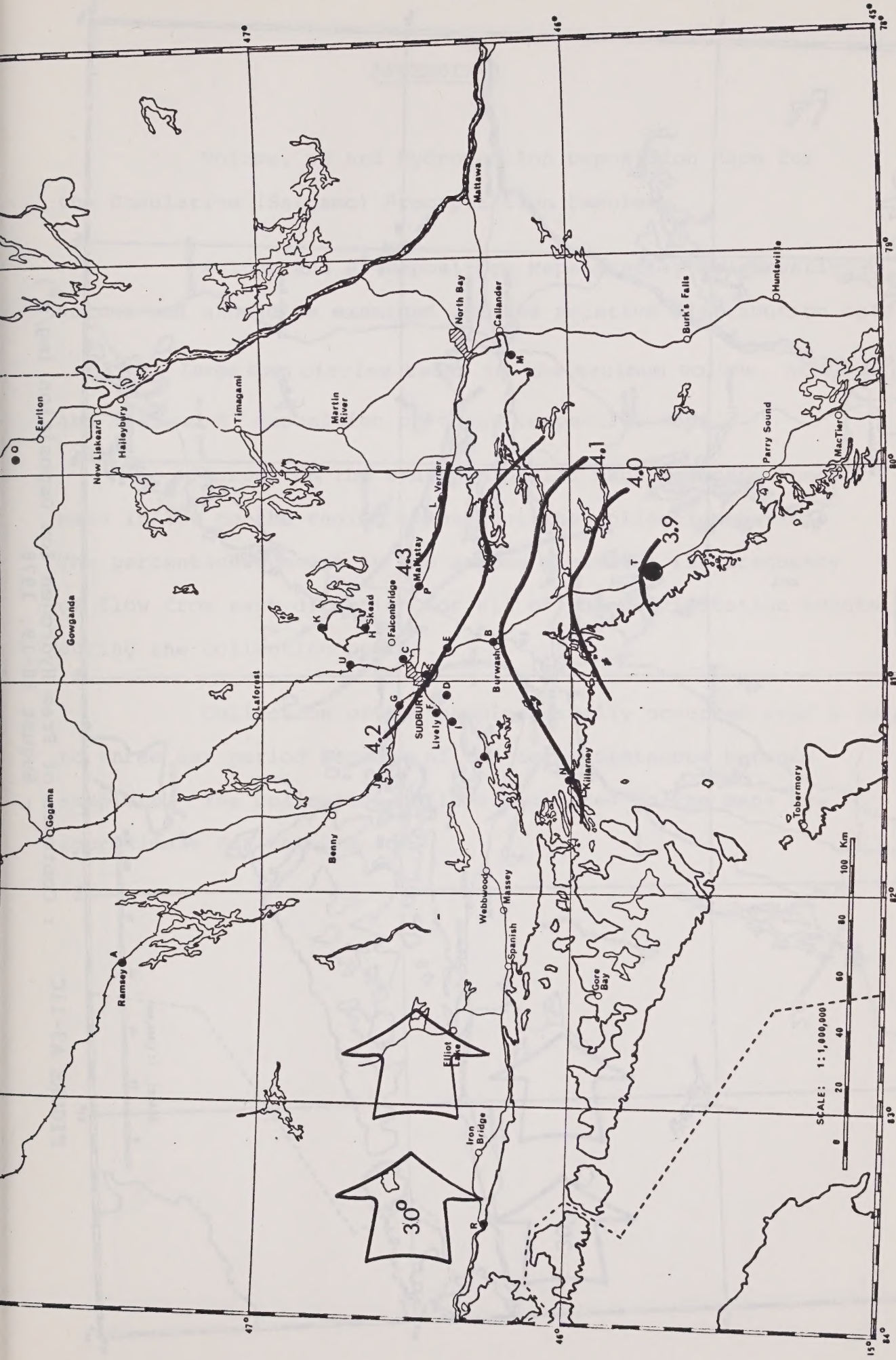


FIGURE A3-11B : Contours of Precipitation pH - August 18-19, 1978

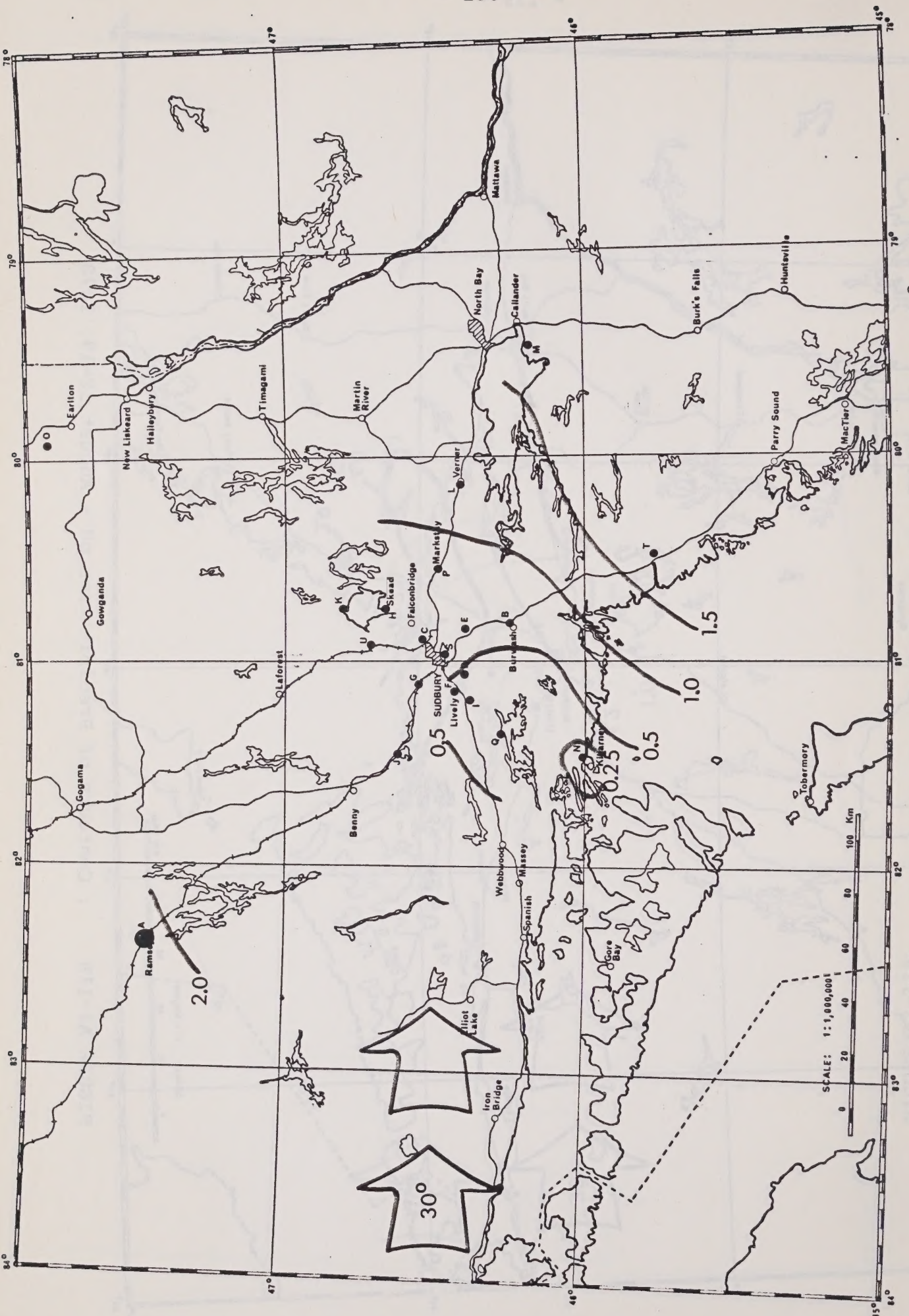


FIGURE A3-11C : Contours of Free Hydrogen Ion Deposition (mg/m^2)
- August 18-19, 1978

APPENDIX 4

Volume, pH and Hydrogen Ion Deposition Maps for the Cumulative (Sangamo) Precipitation Samples.

Volume and H^+ Deposition Maps display conservative values and should be examined for the relative distribution only.

Large open circles refer to the maximum volume, minimum pH and maximum H^+ deposition on their respective maps.

Arrows on the shutdown period maps indicate the air mass inflow to the region throughout the collection period. The percentage numbers in the arrows represent the frequency of flow from each direction for all of the precipitation events during the collection period.

Collection of the samples usually occurred over a two to three day period because of the large distances between samplers. The collection periods indicated on the maps are approximate for this reason.

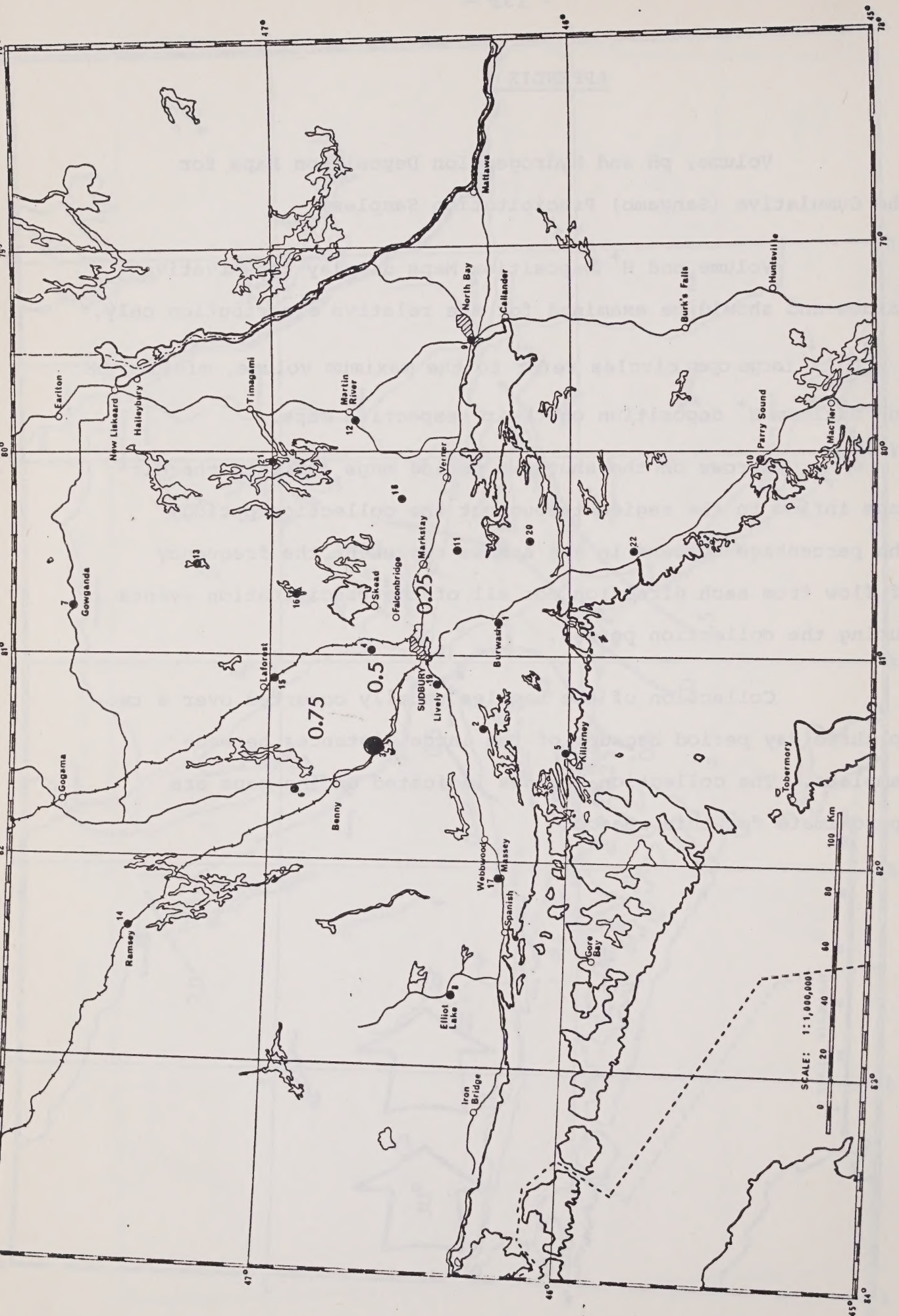


FIGURE A4-1A: Contours of Cumulative Precipitation Volume (1)
Early July, 1978; INCO-only operating period

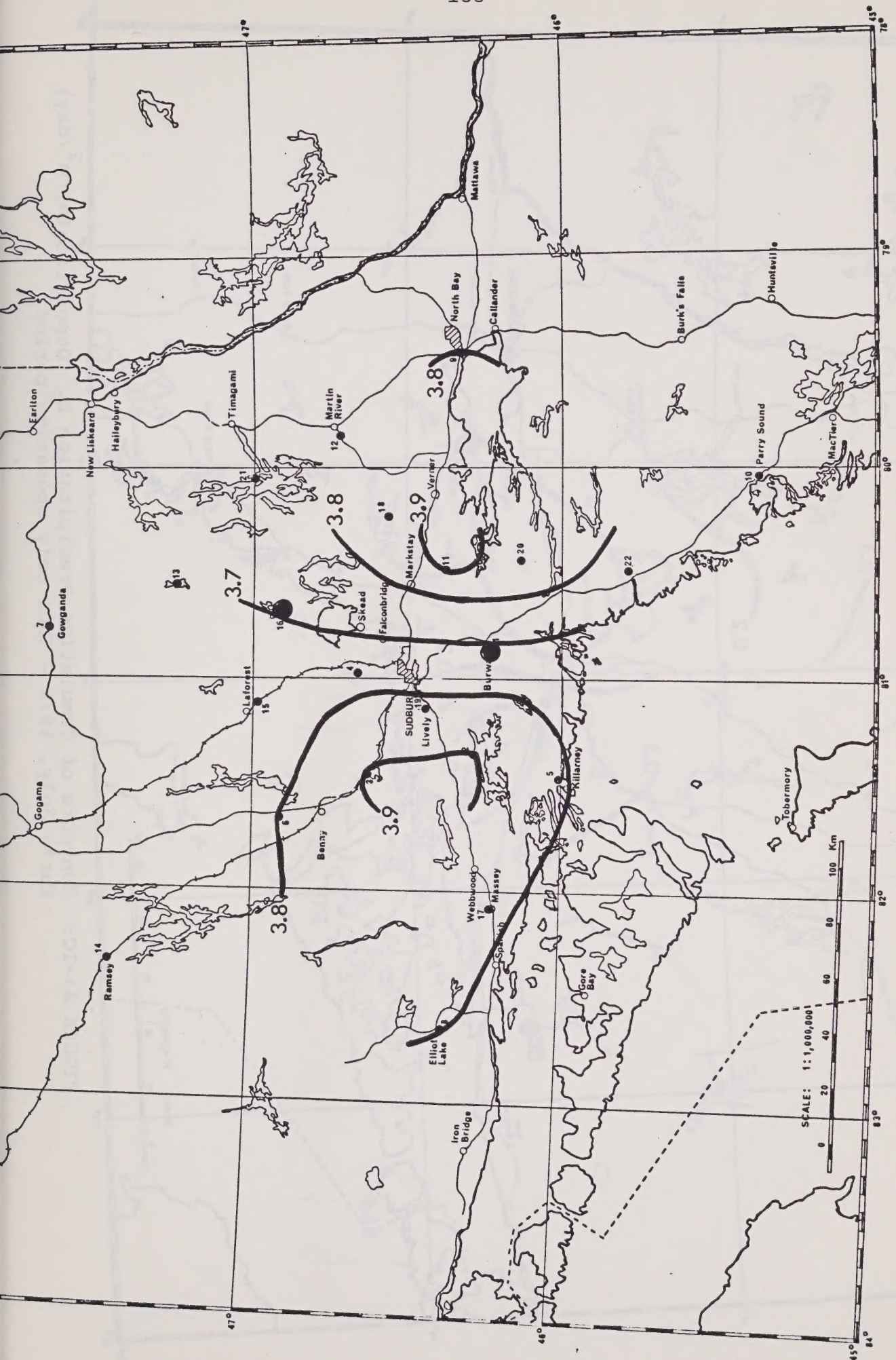


FIGURE A4-1B: Contours of Cumulative Precipitation pH
Early July, 1978 - INCO-only operating period

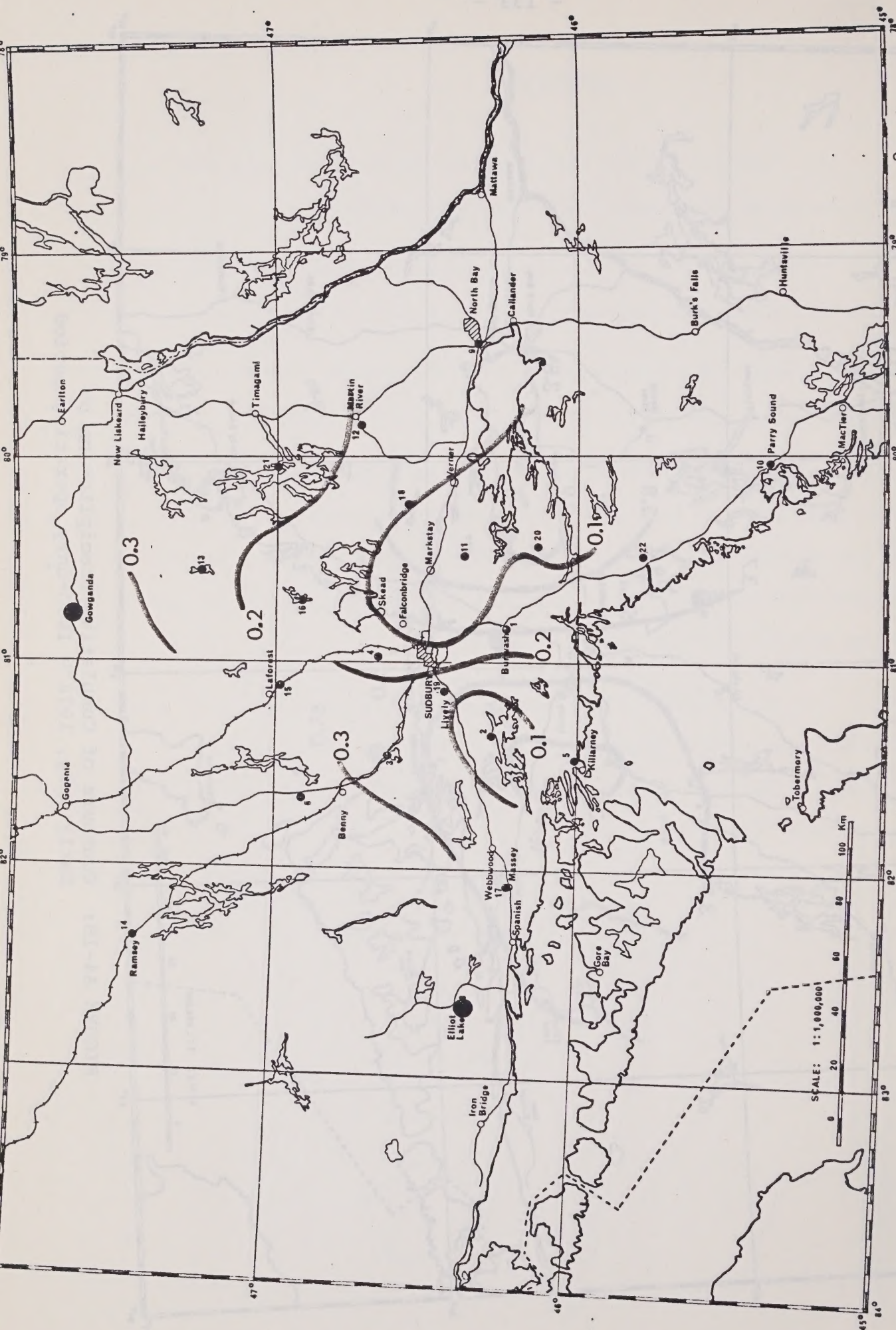


FIGURE A4-1C: Contours of Cumulative Precipitation H_F + Deposition ($\text{mg}/\text{m}^2/\text{day}$)
Early July, 1978 - INCO only operating period

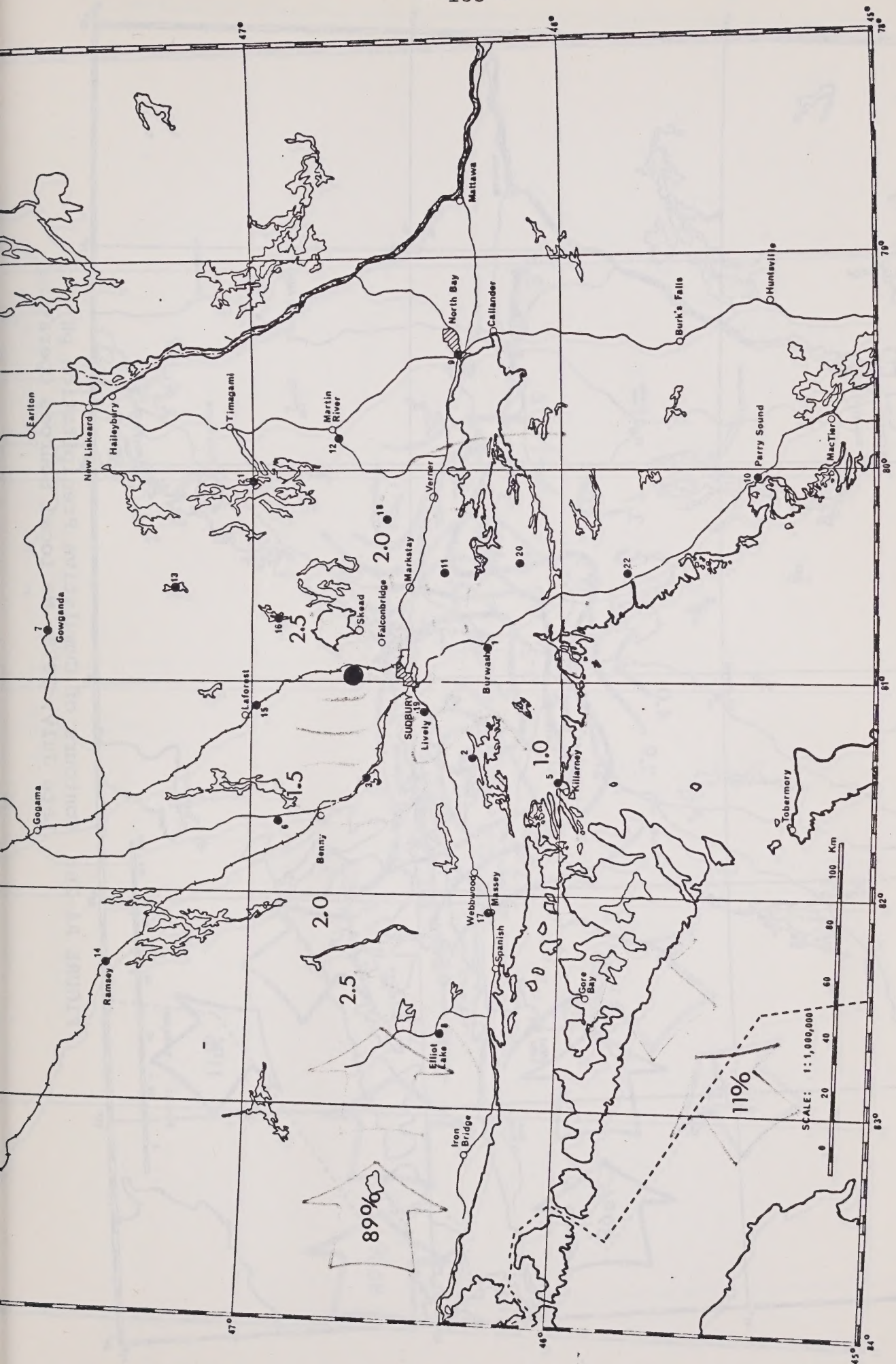


FIGURE A4-2A: Contours of Cumulative Precipitation Volume (1)
Late July, 1978 - No Local Sources Operating

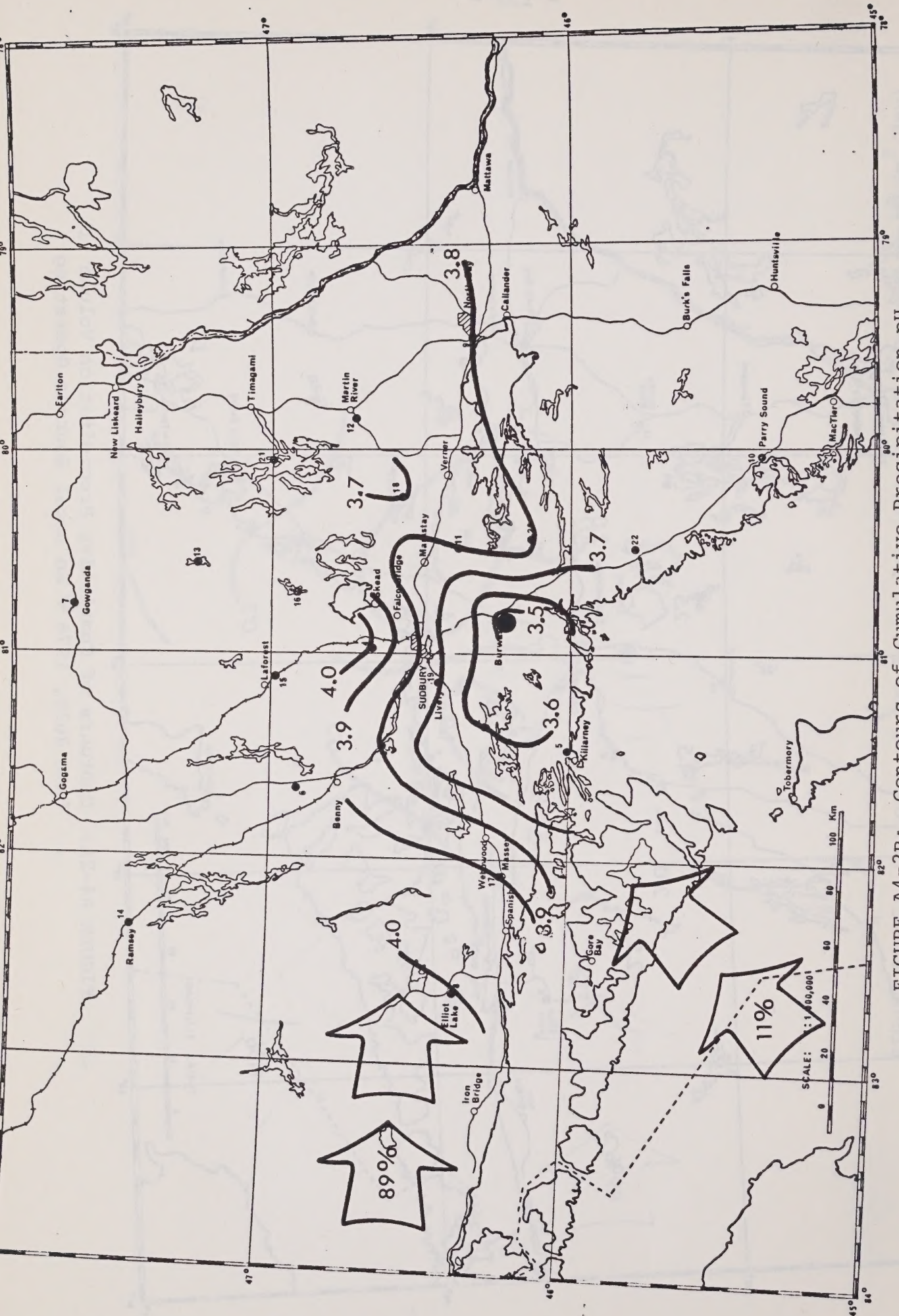


FIGURE A4-2B: Contours of Cumulative Precipitation pH
Late July, 1978; No Local Sources Operating

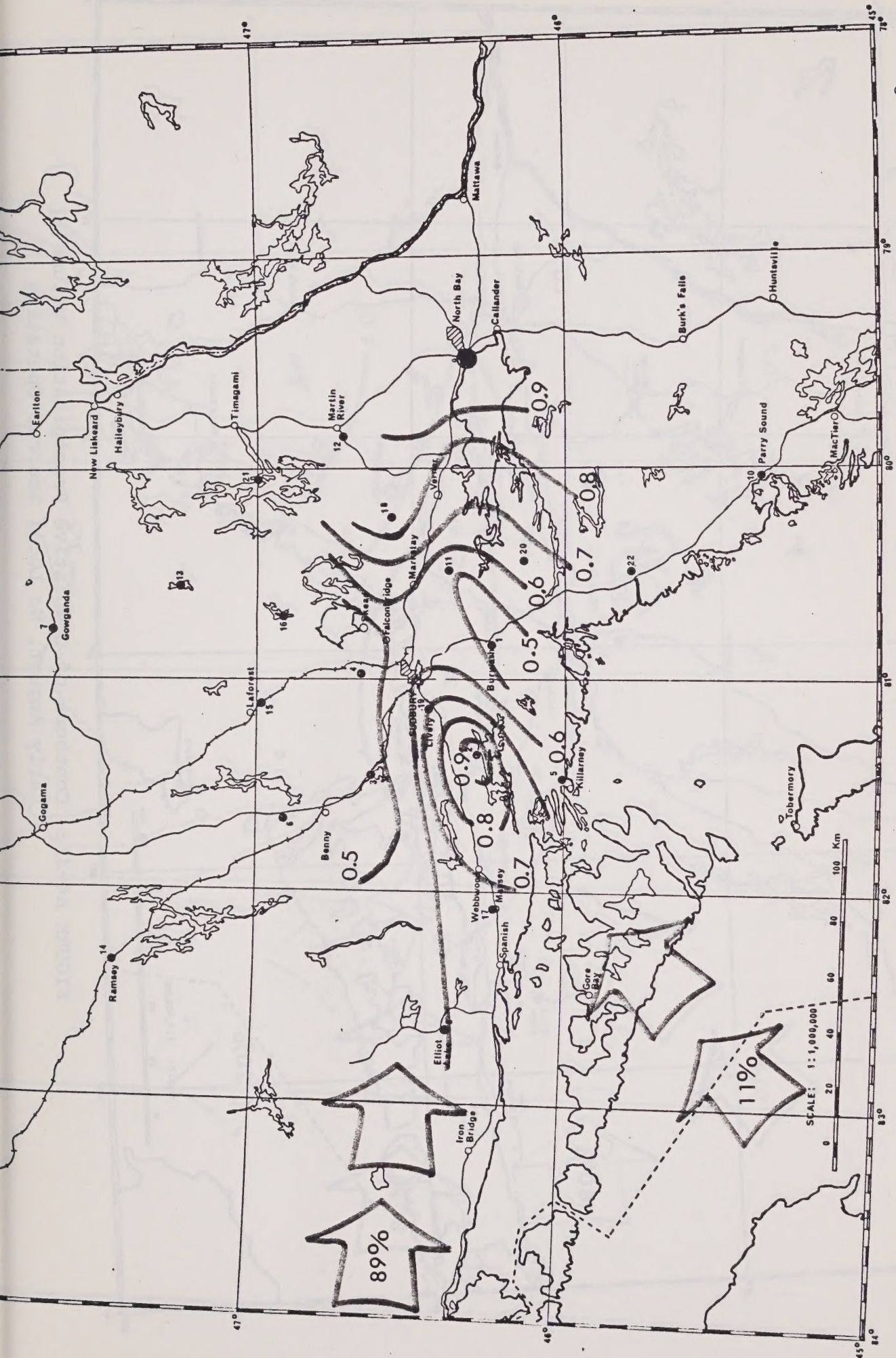


FIGURE A4-2C: Contours of Cumulative Precipitation H_f^+ Deposition ($\text{mg}/\text{m}^2/\text{day}$)
Late July, 1978 - No Local Sources Operating

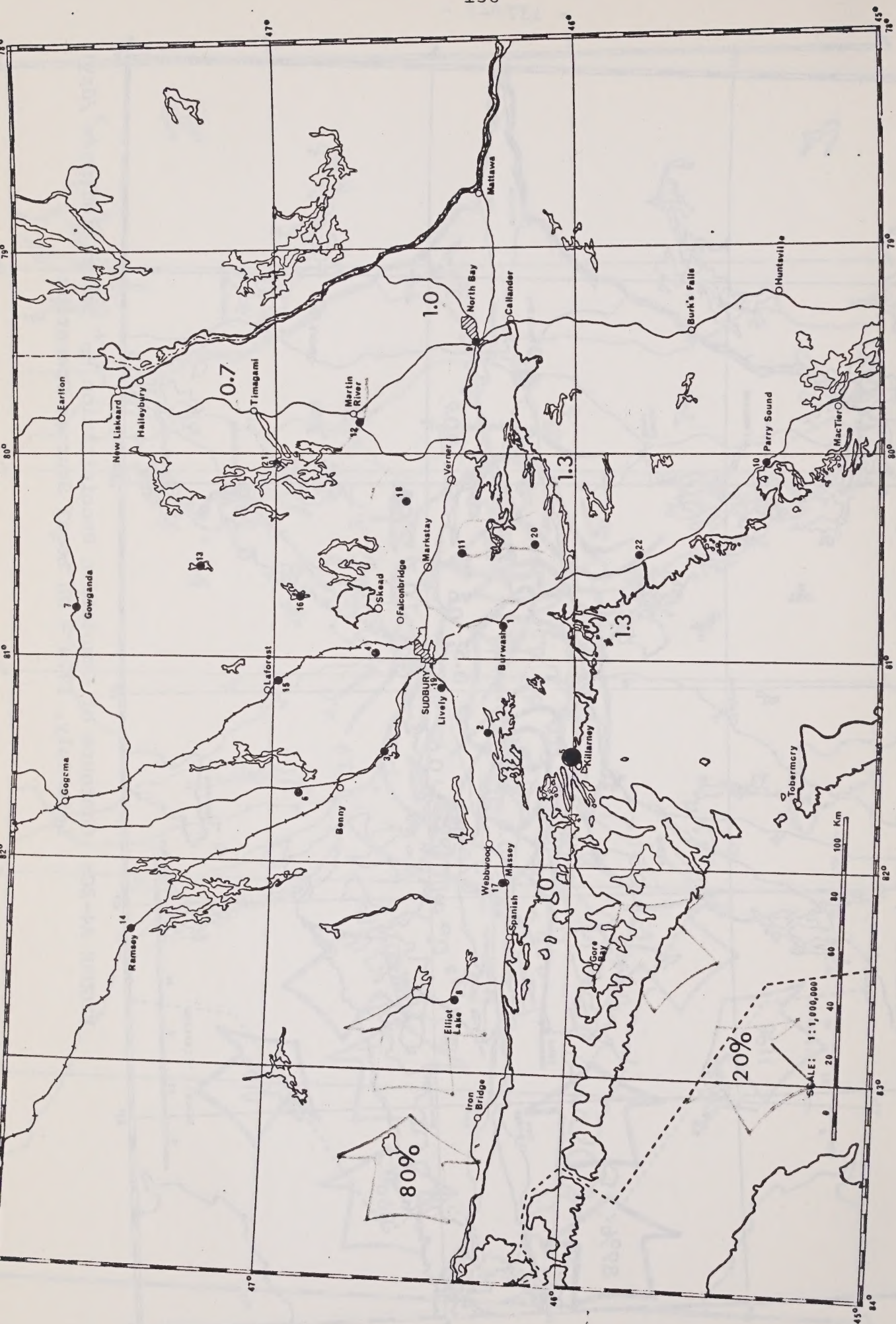


FIGURE A4-3A: Contours of Cumulative Precipitation Volume(1)
Early August, No Local Sources Operating

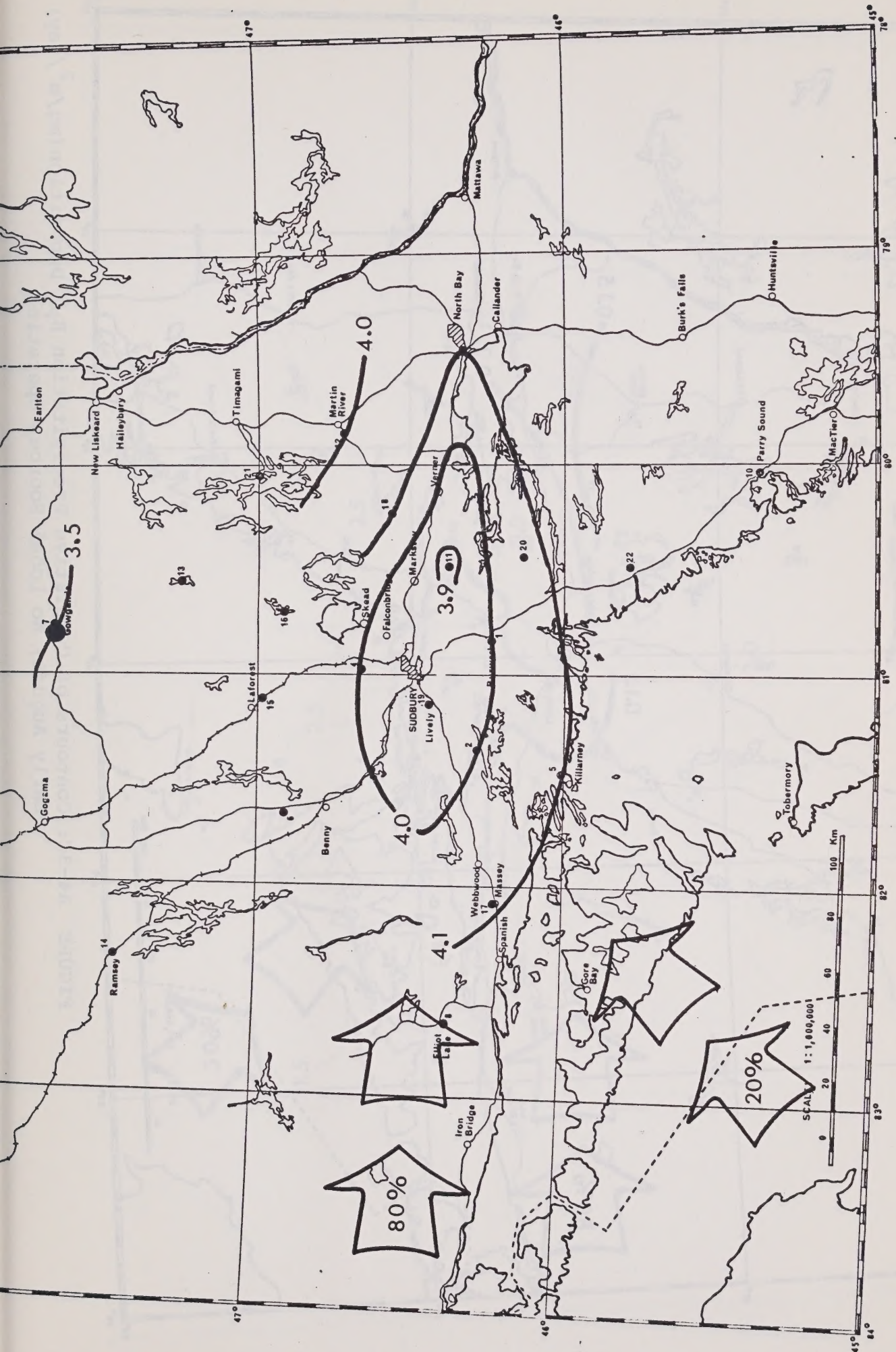


FIGURE A4-3B: Contours of Cumulative Precipitation pH
Early August; No Local Sources Operating

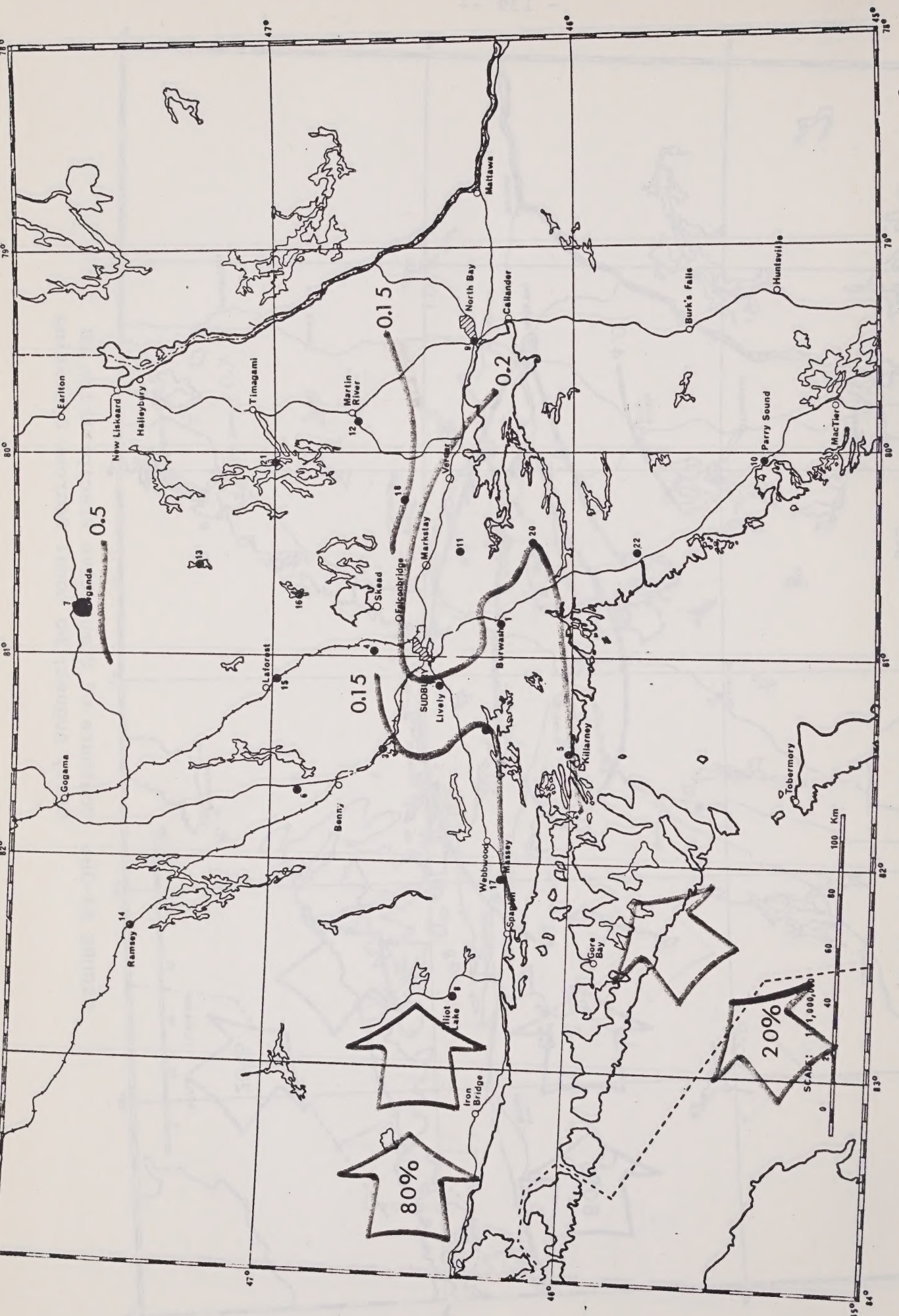


FIGURE A4-3C: Contours of Cumulative Precipitation H_f^+ Deposition ($\text{mg}/\text{m}^2/\text{day}$)
Early August; No Local Sources Operating

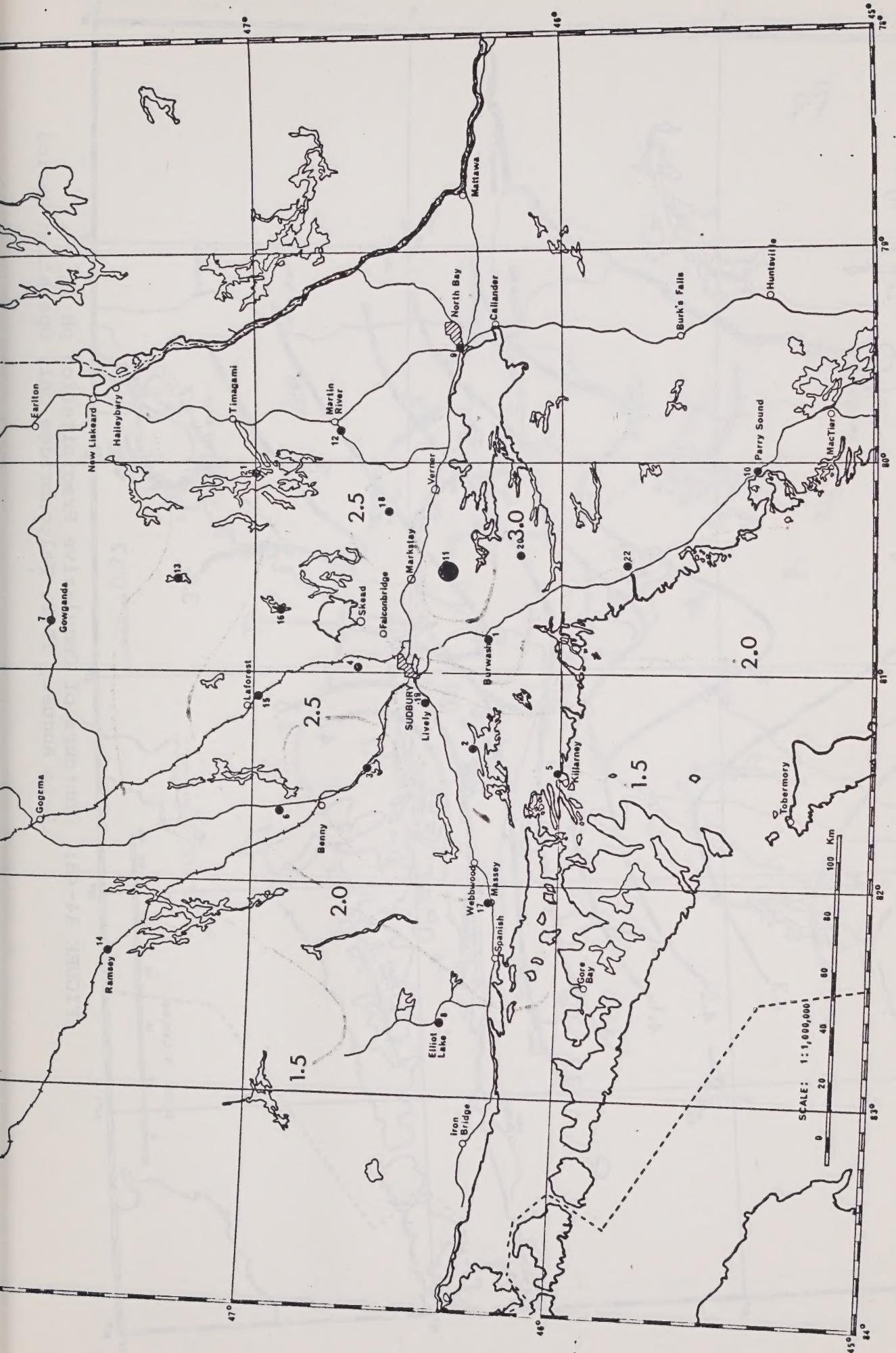


FIGURE A4-4A: Contours of Cumulative Precipitation Volume (1)
Late August, 1978 Falconbridge only Operating Period

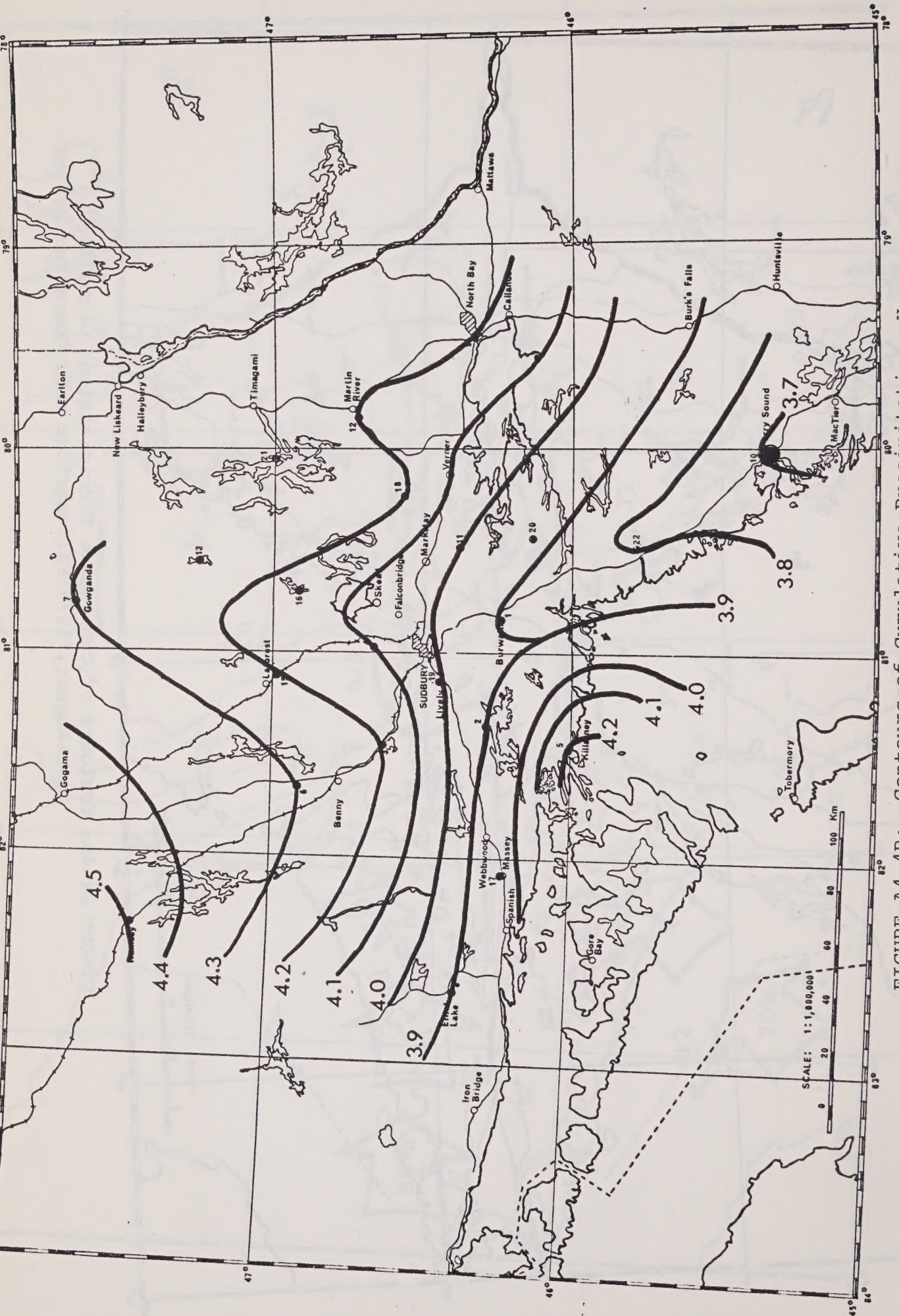


FIGURE A4-4B: Contours of Cumulative Precipitation pH
Late August, 1978, Falconbridge only Operating Period

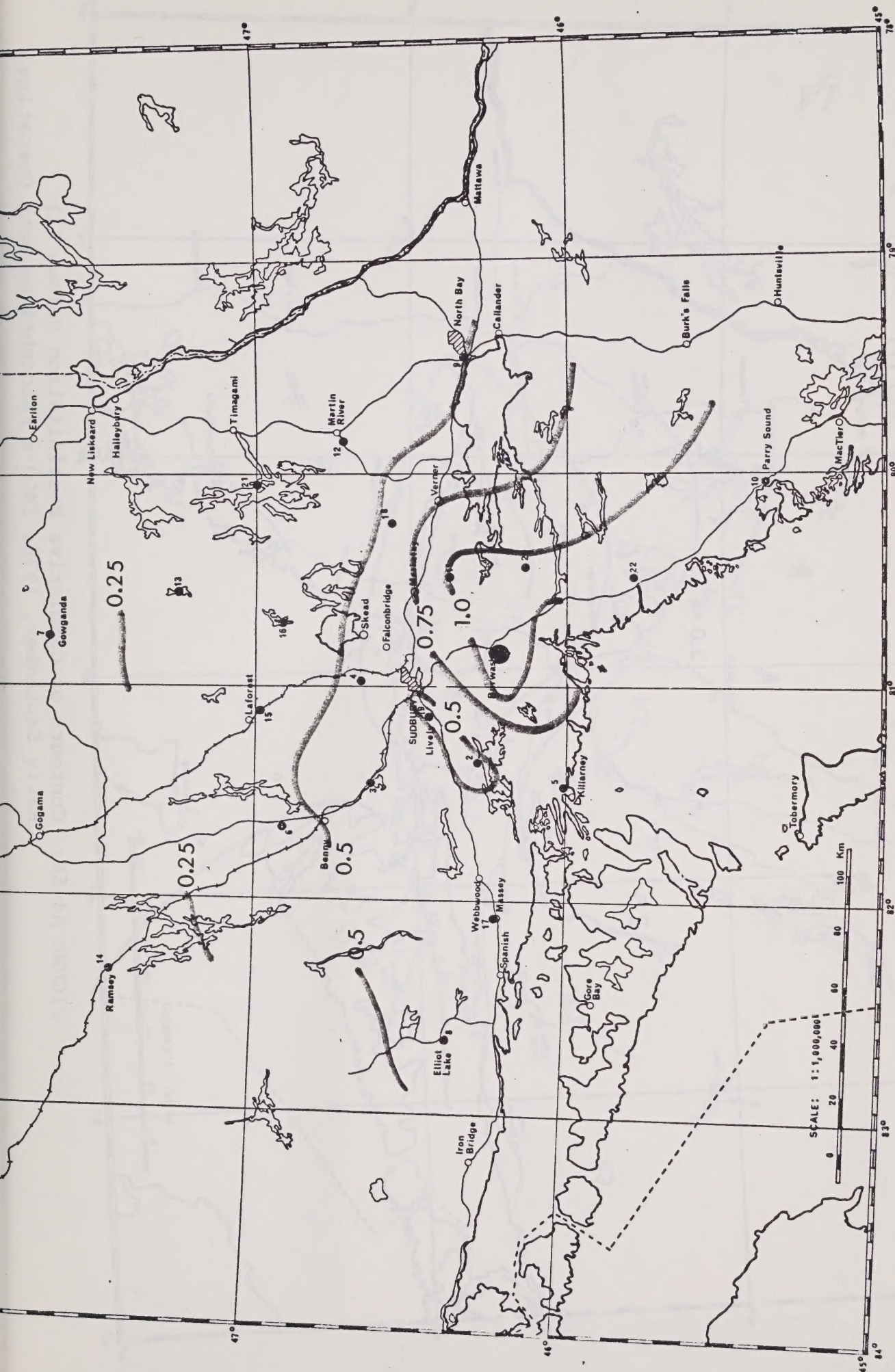


FIGURE A4-4C: Contours of Cumulative Precipitation H_F^+ Deposition ($\text{mq}/\text{m}^2/\text{day}$)
Late August, 1978, Falconbridge Only Operating Period

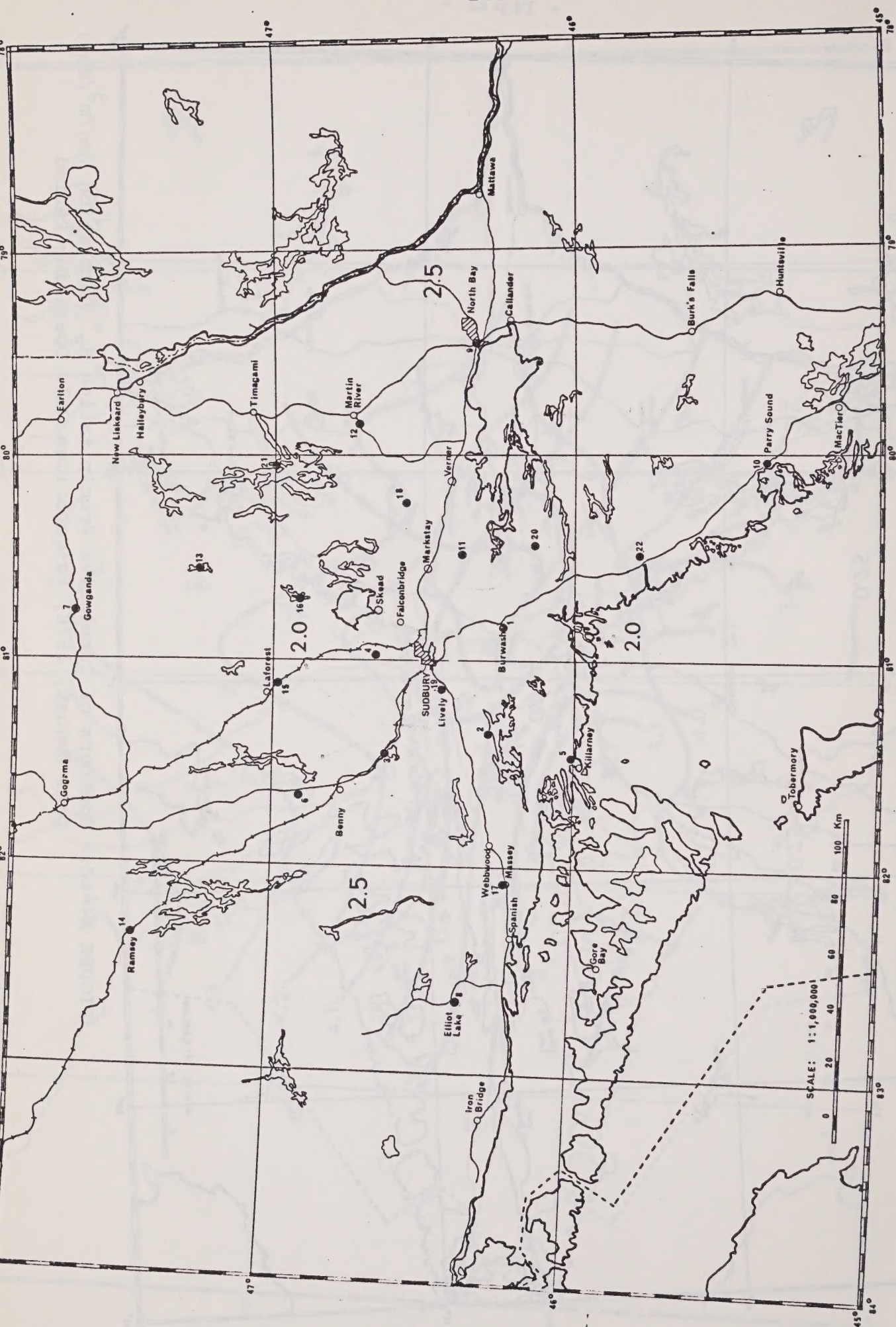


FIGURE A4-5A: Contours of Cumulative Precipitation Volume (1)
Early September, 1978. INCO & Falconbridge Both Operating

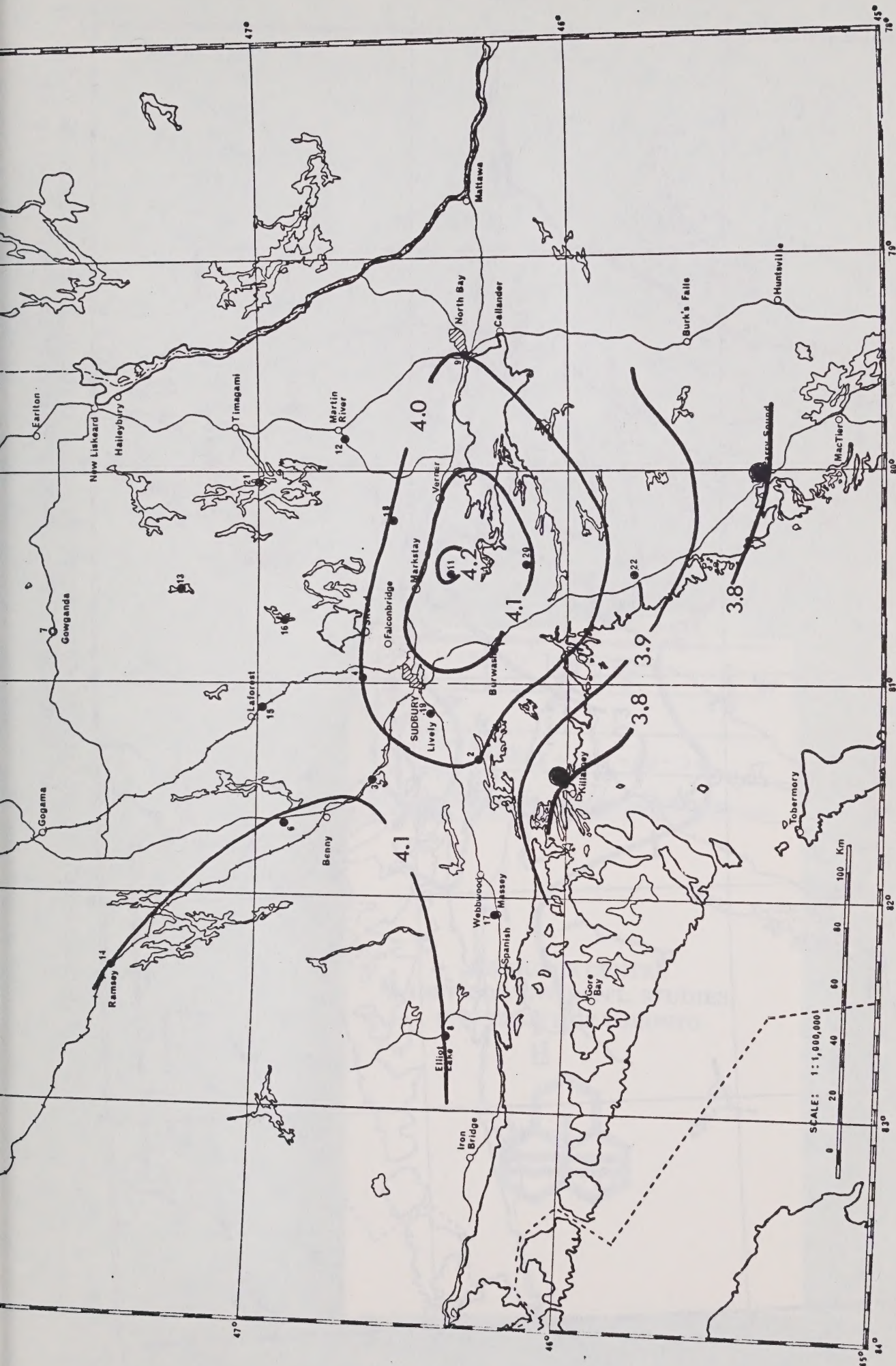


FIGURE A4-5B: Contours of Cumulative Precipitation pH
Early September, 1978 INCO & Falconbridge Both Operating

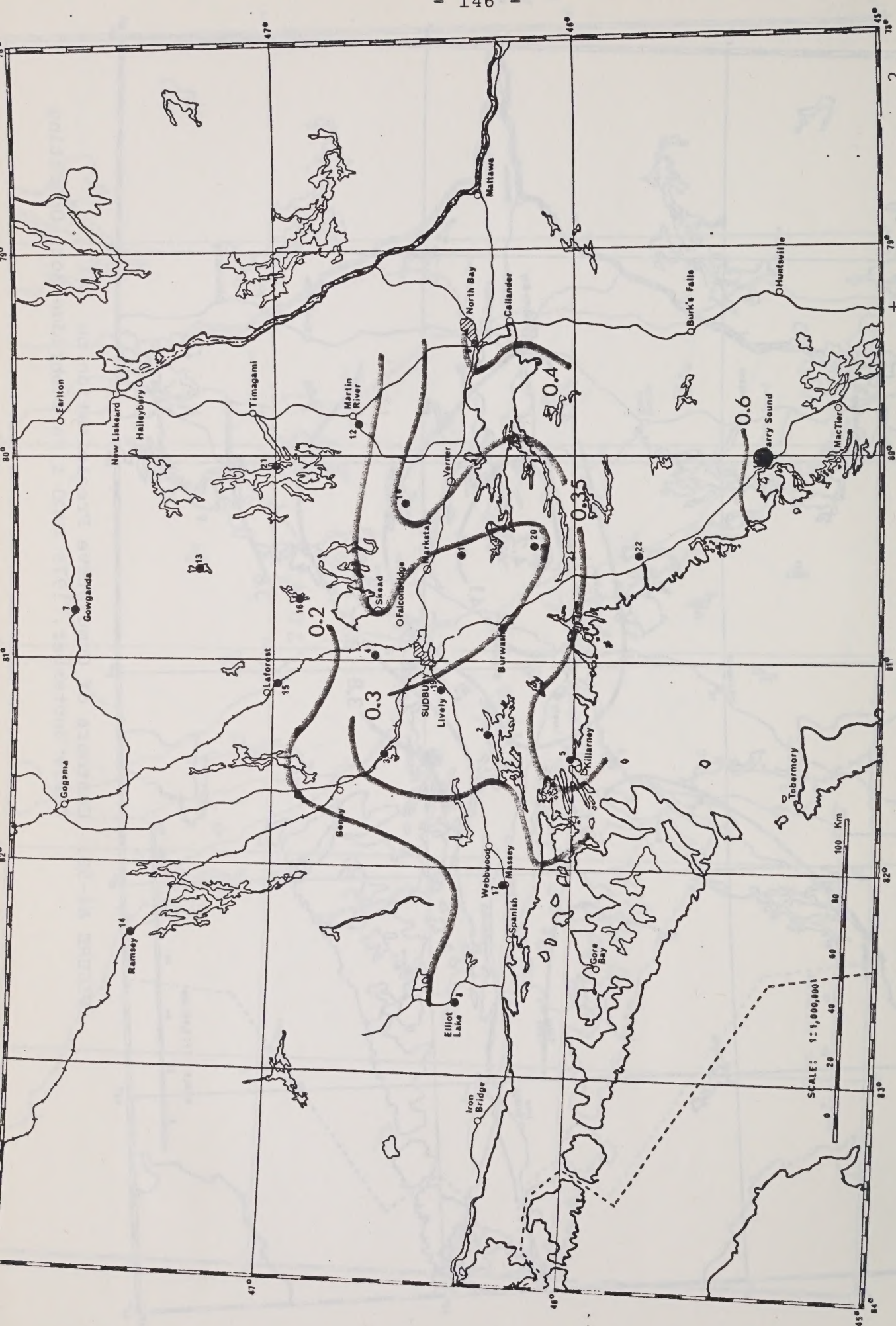


FIGURE A4-5C: Contours of Cumulative Precipitation H_F + Deposition (mm^2/day) Early September, 1978, INCO & Falconbridge Both Operating

Doc. No.	Corporate Author:
042	Ont. M.O.E.
ONEV	
58	Series:
79	ARB-TDA-84-79
879	Title:
	Analysis of The Sudbury

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